ADA122963

(12)

AFWAL-TR-82-4136

EFFECTS OF MANUFACTURING PROCESSES ON STRUCTURAL ALLOWABLES

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

November 1982

Final Report for Period Sept. 1980 to July 1982

Approved for public release; distribution unlimited.

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

DTIC FILE COPY

DTIC
ELECTE
JAN 4 1983
S D
A

82 [illegible] 03 002

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

N. R. Ontko

N. R. ONTKO
Project Engineer
Materials Integrity Branch

Clayton L Harmsworth

CLAYTON L. HARMSWORTH
Technical Manager for
Engineering & Design Data
Materials Integrity Branch

FOR THE COMMANDER

T. D. Cooper

T. D. Cooper, Chief
Materials Integrity Branch
Systems Support Division
Materials Laboratory/MLSA

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify AFWAL/MLSA W-PAFB, OH 45433 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFWAL-TR-82-4136	2. GOVT ACCESSION NO.: AD-A122 963
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): EFFECTS OF MANUFACTURING PROCESSES ON STRUCTURAL ALLOWABLES	5. TYPE OF REPORT & PERIOD COVERED: Final Sept. 1980 - July 1982
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Dana J. Jones, and Stephen C. Ford	8. CONTRACT OR GRANT NUMBER(s): F33615-80-C-5168
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Battelle's Columbus Laboratories, 505 King Avenue, Columbus, OHio 43201	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element 78011F
11. CONTROLLING OFFICE NAME AND ADDRESS: Materials Laboratory (AFWAL/MLSA), AF Wright Aeronautical Laboratories (AFSC), Wright-Patterson Air Force Base, Ohio 45433	12. REPORT DATE: November 1982
	13. NUMBER OF PAGES: 161
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mechanical Properties	Powder Metallurgy	Ti-6Al-4V (CHIP)
Fatigue Properties	Aluminum Alloys	Ti-10V-2Fe-3Al
Fracture Toughness	Titanium Alloys	CT-91-T7E69
Crack Propagation	Steel Alloys	AF 1410 Forging/Plate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The major objective of this program was to evaluate the effect that newly established manufacturing techniques will have on the handbook properties of structural materials which have a possible use in Air Force systems. Data-sheet-type presentations of engineering properties were prepared for each material.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report was prepared by Battelle's Columbus Laboratories under Contract F33615-80-C-5178. The program was administered under the direction of the Materials Laboratory (AFWAL), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal R. Ontko, Engineering and Design Data, Materials Integrity Branch.

This final report covers work conducted from September 1980 to Jul 1982. The report was submitted by the authors on July 8, 1982.

The authors wish to express their appreciation to B. Leis, P. Ruff, R. Rungta, O. Deel, N. Frey, E. Swetnam, and J. VanEcho for their assistance and support on the program.

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

COPY INSPECTED 2

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Testing Procedures	1
Ti-6Al-4V Alloy (CHIP)	4
CT-91-T7E69 Aluminum	28
Ti-10V-2Fe-3Al Isothermally Forged Pancake	55
Appendix A - Data Sheets	76
Appendix B - Specimen Drawings	101
Appendix C - AF 1410 Supplemental Data	111

LIST OF ILLUSTRATIONS

		Page
Figure 1.	Typical tensile stress-strain curves for annealed Ti-6Al-4V (CHIP) alloy	18
2.	Effect of temperature on the tensile properties of annealed Ti-6Al-4V (CHIP) alloy	19
3.	Typical compressive stress-strain curves for annealed Ti-6Al-4V (CHIP) alloy	20
4.	Typical compressive tangent-modulus curves for annealed Ti-6Al-4V (CHIP) alloy	21
5.	Effect of temperature on the compressive properties of annealed Ti-6Al-4V (CHIP) alloy	22
6.	Effect of temperature on the pin shear properties of annealed Ti-6Al-4V (CHIP) alloy	22
7.	Effect of temperature on the bearing properties of annealed Ti-6Al-4V (CHIP) alloy	23
8.	Typical bearing test specimen for annealed Ti-6Al-4V (CHIP) alloy after testing (e/D = 1.5)	24
9.	Typical bearing test specimen for annealed Ti-6Al-4V (CHIP) alloy after testing (e/D = 2.0)	24
10.	Axial load fatigue behavior of unnotched, annealed Ti-6Al-4V (CHIP) alloy	25
11.	Axial load fatigue behavior of notched (K_t = 3.0), annealed Ti-6Al-4V (CHIP) alloy	25
12.	Stress-rupture and plastic deformation curves for annealed Ti-6Al-4V (CHIP) alloy	26
13.	Plot of da/dN versus delta K for annealed Ti-6Al-4V (CHIP) alloy	27
14.	Location of specimens for CT-91-T7E69	43
15.	Typical tensile stress-strain curves for longitudinal CT-91-T7E69 aluminum extrusion	44
16.	Typical tensile stress-strain curves for long transverse CT-91-T7E69 aluminum extrusion	45
17.	Effect of temperature on tensile properties of CT-91-T7E69 aluminum extrusions	46
18.	Typical compressive stress-strain curves for longitudinal CT-91-T7E69 aluminum extrusion	47
19.	Typical compressive stress-strain curves for long transverse CT-91-T7E69 aluminum extrusion	48

LIST OF ILLUSTRATIONS (Concluded)

		Page
Figure 20.	Typical compressive tangent-modulus curves for longitudinal CT-91-T7E69 aluminum extrusion	49
21.	Typical compressive tangent-modulus curves for long transverse CT-91-T7E69 aluminum extrusion	50
22.	Effect of temperature on the compressive properties of CT-91-T7E69 aluminum extrusion	51
23.	Effect of temperature on pin shear properties of CT-91-T7E69 aluminum extrusion	51
24.	Effect of temperature on the bearing properties of CT-91-T7E69 aluminum extrusion	52
25.	Axial load fatigue behavior of unnotched long transverse CT-91-T7E69 aluminum extrusion	53
26.	Axial load fatigue behavior of notched (K_t = 3.0) long transverse CT-91-E7E69 aluminum extrusion	53
27.	Plot of da/dN versus delta K for CT-91-T7E69 aluminum extrusion	54
28.	Specimen location for STA Ti-10V-2Fe-3Al isothermally forged pancake	70
29.	Axial load fatigue behavior of unnotched and notched (K_t = 3.0), STA Ti-10V-2Fe-3Al pancake at room temperature, long transverse	73
30.	Plot of da/dN versus delta K for STA Ti-10V-2Fe-3Al pancake .	74
31.	Plot of da/dN versus delta K for STA Ti-10V-2Fe-3Al pancake .	75

LIST OF TABLES

		Page
Table 1.	Tensile Test Results for Annealed Ti-6Al-4V (CHIP) Alloy .	7
2.	Compression Test Results for Annealed Ti-6Al-4V (CHIP) Alloy	8
3.	Results of Shear Pin Tests on Annealed Ti-6Al-4V (CHIP) Alloy	9
4.	Bearing Test Results at e/D = 1.5 and e/D = 2.0 for Annealed Ti-6Al-4V (CHIP) Alloy	10
5.	Fracture Toughness Test Results for Annealed Ti-6Al-4V (CHIP) Alloy at Room Temperature	11
6.	Axial Load Fatigue Test Results for Unnotched Annealed Ti-6Al-4V (CHIP) Alloy at a Stress Ratio of R = 0.1 . . .	12
7.	Axial Load Fatigue Test Results for Notched (K_t = 3.0) Annealed Ti-6Al-4V (CHIP) Alloy at a Stress Ratio of R = 0.1	13
8.	Summary Data on Creep and Stress-Rupture Properties of Annealed Ti-6Al-4V (CHIP) Alloy at 800 F (700 K)	14
9.	Results of Stress-Corrosion-Cracking Tests at Room Temperature for Annealed Ti-6Al-4V (CHIP) Alloy	15
10.	Fatigue-Crack-Propagation Data for Annealed Ti-6Al-4V (CHIP) Alloy	16

LIST OF TABLES (Concluded)

		Page
Table 11.	Tensile Test Results for CT-91-T7E69 Aluminum Extrusion . .	30
12.	Compressive Test Results for CT-91-T7E69 Aluminum Extrusion	31
13.	Results of Pin Shear Tests on CT-91-T7E69 Aluminum Extrusion	32
14.	Bearing Test Results at e/D = 1.5 and e/D = 2.0 for CT-91-T7E69 Aluminum Extrusion	33
15.	Fracture Toughness Test Results for CT-91-T7E69 Aluminum Extrusion at Room Temperature	34
16.	Axial Load Unnotched Fatigue Test Results for CT-91-T7E69 Aluminum Extrusion - Long Transverse	35
17.	Axial Load, Notched (K_t = 3.0) Fatigue Test Results for CT-91-T7E69 Aluminum Extrusion - Long Transverse	36
18.	Results of the Stress-Corrosion-Cracking Tests at Room Temperature for CT-91-T7E69 Aluminum Extrusion L-T Specimens	37
19.	Fatigue-Crack-Propagation Data for CT-91-T7E69 Aluminum Extrusion, L-T Specimens	38
20.	Tensile Test Results for STA Ti-10V-2Fe-3Al Pancake	57
21.	Room Temperature Compression Test Results for STA Ti-10V-2Fe-3Al Pancake	58
22.	Pin Shear Test Results for STA Ti-10V-2Fe-3Al Pancake . . .	59
23.	Bearing Test Results at e/D = 1.5 and e/D = 2.0 for STA Ti-10V-2Fe-3Al Pancake	60
24.	Axial Load Unnotched Fatigue Test Results at Room Temperature for STA Ti-10V-2Fe-3Al Pancake - Long Transverse . .	61
25.	Axial Load Notched (K_t = 3.0) Fatigue Test Results at Room Temperature for STA Ti-10V-2Fe-3Al Pancake - Long Transverse	62
26.	Fatigue-Crack-Propagation Data for STA Ti-10V-2Fe-3Al Pancake at Room Temperature - L-T Specimen	63
27.	Fatigue-Crack-Propagation Data for STA Ti-10V-2Fe-3Al Pancake at 600 F (589 K) - L-T Specimen	67

INTRODUCTION

Materials for United States Air Force advanced weapons systems must meet new combinations of design load and damage tolerance requirements as well as tightened economic and environmental constraints. New alloys and modifications in manufacturing processing or product forms of existing alloys are continually being developed to meet these increased demands. However, many potentially attractive materials or processes are either in the final development stage or have just become commercially available and, as such, engineering data adequate for comparison purposes are not available.

The Air Force, in recognition of this fact, has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for these materials and processes. The results of these programs have been published in numerous technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, AFML-TR-72-196 (Volumes I and II), AFML-TR-73-114, AFML-TR-75-97, AFML-TR-77-198, AFML-TR-78-179, and AFWAL-TR-80-4103.

This report presents the results of evaluations of three materials produced by powder metallurgy processes. These materials are as follows:

(1) Ti-6Al-4V alloy, cold isostatically pressed, vacuum sintered, and hot isostatically pressed

(2) CT-91-T7E69 aluminum alloy, extruded bar

(3) Ti-10V-2Fe-3Al alloy, isothermally forged pancake

The engineering property data sheets issued on the above materials are reproduced in Appendix A of this report.

A data sheet was developed on AF 1410 material and issued in early 1978. However, because of concern for the sensitivity of the material to heat treatment and those effects upon fatigue, the full data package was withheld from publication in AFML-TR-78-179. Since it appears that additional fatigue data will not be developed in the near future, the full data package is included in Appendix C.

Testing Procedures

Certain standard testing procedures for evaluating some of the basic properties of metals have been well established for many years. Other testing procedures, such as those used for measuring fracture toughness and crack propagation, have not been standardized completely and sometimes require considerable judgment in selecting appropriate specimens, conducting the tests, and interpreting the data. To obtain the most useful information from these evaluations and a thorough understanding of the significance of the data, close liaison was maintained between the Project Monitor and Battelle's Columbus Laboratories.

In discussing the testing procedures in the following paragraphs, emphasis is given to procedures not covered in detail in standard specifications. All testing was performed in a laboratory air environment except for the stress corrosion evaluations.

Testing of the Ti-6Al-4V (CHIP) and CT-91-T7E69 alloys was accomplished by Battelle and followed the procedures described below. Testing of the Ti-10V-2Fe-3Al alloy was performed by the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base.

Specimen drawings are shown in Appendix B of this report.

Tension Tests. Tension-test specifications are covered by ASTM Methods E8 and E21. These specifications were followed in measuring tensile yield strength at 0.2 percent offset, ultimate strength, elongation, and reduction in area.

For elevated-temperature tensile tests, specimens were held at the test temperature from 15 to 30 minutes before loading. The strain rate was 0.005 inch per inch per minute (0.005 mm/mm/min), as indicated by a strain pacer, until the yield strength was exceeded and then the speed was 0.1 inch per inch per minute (0.1 mm/mm/min) until fracture. Averaging-type extensometers with extensions to position the linear differential transformer unit out of the furnace were used with appropriate autographic recorders to plot load-strain curves to past the yield load. The extensometer-recorder combination was calibrated regularly as a unit. Yield strengths were measured from the load-strain curves at 0.2 percent offset. Young's modulus values also were measured from the load-strain curves.

Compression Tests. ASTM Method E9 and temperature-control provisions of E21 were used in measuring compressive modulus and compressive yield strength at 0.2 percent offset.

For cylindrical specimens the ends were machined paralled to within 0.0002 inch (0.0051 mm) and fixturing was used to maintain alignment during testing. The strain rate was 0.005 inch per inch per minute (0.005 mm/mm/min) to past the yield load. The specimens were instrumented to assure adequate temperature control. Data reported were compressive yield strength and compressive modulus at room temperature and at two elevated temperatures.

Shear Tests. A 0.250 inch (6.35 mm) double-shear specimen was used with conventional equipment.

Bearing Tests. Bearing tests were conducted in accordance with ASTM E238. All tests were "clean pin" tests as defined in the above specification. The data reported are ultimate bearing strength and bearing yield strength at e/D ratios of 1.5 and 2.0.

Fracture-Toughness Testing. Compact-tension specimens of appropriate dimensions were utilized in accordance with ASTM E399 for fracture toughness tests.

Fatigue Tests. Fatigue testing was conducted according to ASTM E466. Tests were performed on unnotched and notched ($K_t = 3.0$) specimens in axial-tension loading to define an S-N curve between 10^3 and 10^7 cycles. The stress ratio for all tests was R = 0.1.

Elevated temperatures were attained by using induction heating. Thermocouples attached to the specimens were used to adjust and control temperatures in conjunction with appropriate temperature controllers. The critical gage section of the specimens was held at temperature for approximately 10 minutes prior to stress application. When specimen failure occurred, the fatigue machine and heater automatically stopped.

Creep Tests. Standard creep-testing frames, using deadweight loading of the specimen, were employed. These machines are calibrated within the requirements of ASTM E139. Chromel A and platinum heater wire furnaces with taps along the side that allow for correcting small temperature differences ($\pm$ 2 F, $\pm$ 1.1 K) along the gage length of the specimen were utilized. Windows in the front or back of the furnaces allowed creep measurements to be made optically using platinum strip extensometers attached either directly to the gage section or on the shoulder of the specimen. The microscopes for these optical measurements were fitted with filar eyepieces whose smallest division corresponds to a 1 inch (2.54 cm) gage length to a strain of 0.005 percent. Zero reading was taken after the specimen reached the test temperature with no stress applied. The initial deformation was obtained by applying the entire stress as rapidly as possible. Foxboro temperature controllers operating on high-low power input, controlled the test temperature to within about 1.5 F (0.8 K) of the intended temperature. A minimum of three thermocouples were attached to the gage section of each specimen. The thermocouples were made from calibrated wire and new couples were employed for each test.

Stress-Corrosion Cracking. Increasing K tests at room temperature were conducted using a chamber on the specimen to hold a flow of 3½% NaCl. Precracked compact tension type specimens were used.

Crack-Growth Testing (da/dN). Constant-amplitude tests at a stress ratio of R = 0.1 were conducted in accordance with ASTM E647. A compact tension specimen was used. Emphasis was placed on data within a da/dN range of 10^{-4} to 10^{-7} inch/cycle.

Ti-6Al-4V Alloy (CHIP)

Material Description

This Ti-6Al-4V alloy, a powder metallurgy product from Dynamet Technology, was received in the form of sixty 5/8" (1.59 cm) diameter x 5" (13 cm) bars, seven 0.125" (0.318 cm) x 2" (5 cm) x 12" (30 cm) strips, and nine 3/4" (1.9 cm) x 3" (8 cm) x 3" (8 cm) blanks.

The chemical composition of this lot was as follows:

Chemical Composition	Percent Weight
Aluminum	5.70
Vanadium	4.22
Carbon	0.024
Hydrogen	0.0013
Nickel	0.0112
Oxygen	0.10
Others	0.43
Titanium	Balance.

The nine 3/4" (1.9 cm) x 3" (8 cm) x 3" (8 cm) blanks were used to make the compact tension specimens. The sixty 5/8" (1.59 cm) diameter x 5" (13 cm) bars were used for tensile, compressive, shear, and fatigue specimens, and the 0.125" (0.318 cm) x 2" (5 cm) x 12" (30 cm) strips were used for bearing specimens.

Processing and Heat Treating

The Ti-6Al-4V alloy was received in the "CHIP"ed condition. "CHIP" (Cold Hot Isostatically Pressed) processing means the material was cold isostatically pressed at 60,000 psi (413.7 MPa), vacuum sintered at 2250 F (1505 K) for 3 hours and furnace cooled, and hot isostatically pressed at 15,000 psi (103.4 MPa) at 1650 F (1172 K) to achieve the desired density and mechanical properties. The above conditioning left the material in an annealed state.

Test Results

The results of this evaluation show strength values comparable to wrought annealed material. The tensile and compression strengths were slightly lower while the bearing and shear strengths were slightly higher.

Tension. Tests were conducted at 78 F (299 K), 400 F (478 K), and 800 F (700 K), with the test results shown in Table 1. Typical stress-

strain curves at temperature are presented in Figure 1. The effect-of-temperature curves are displayed in Figure 2.

Compression. Tests were conducted at 78 F (299 K), 400 F (478 K), and 800 F (700 K), with the results shown in Table 2. Typical stress-strain and tangent-modulus curves are presented in Figures 3 and 4. Effect-of-temperature curves are shown in Figure 5.

Shear. Tests were conducted at 70 F (294 K), 400 F (478 K), and 800 F (700 K), with the results shown in Table 3. Figure 6 shows the effect-of-temperature curve.

Bearing. Results of the bearing tests (e/D = 1.5, e/D = 2.0) at 70 F (294 K), 400 F (478 K), and 800 F (700 K) are presented in Table 4. Effect-of-temperature curves are shown in Figure 7. Photographs of some typical failures are shown in Figures 8 and 9.

Fracture Toughness. Results of compact-tension-type specimen tests at 68 F (293 K) are shown in Table 5. The calculated K_Q values shown are valid K_{Ic} values per ASTM E399.

Fatigue. The axial-load fatigue test results on unnotched and notched (K_t = 3.0) specimens at 74 F (296 K) and 800 F (700 K) are presented in Tables 6 and 7. S-N curves are shown in Figures 10 and 11.

Creep and Stress Rupture. Tests were conducted at 800 F (700 K). Due to the small amount of creep before rupture, only 0.2 percent deformation data could be obtained on most specimens. The results are presented in Table 8, while log-stress versus log-time curves are shown in Figure 12.

Stress-Corrosion-Cracking. Increasing K tests were conducted at 75 F (297 K). A value of 15 ksi$\sqrt{in}$ (16.5 MPa$\cdot$m^{½}) for K_{Iscc} at 10^{-8} in/sec (25.4×10^{-8} mm/sec) was determined as a best approximation. Results of the tests are given in Table 9.

Crack Growth. Results of the fatigue-crack-propagation tests are presented in Table 10, and are shown in Figure 13. Compact-tension-type specimens were used with a stress ratio of R = 0.1.

Thermal Expansion. The value supplied by Dynamet Technology for the coefficient of thermal expansion is 6.0×10^{-6} in/in/F (70-800 F) [10.8×10^{-6} m/(m$\cdot$k) (295-700 K)].

Density. The value of density supplied by Dynamet Technology is 0.159 lb/in^3 (4.41 g/cm^3).

TABLE 1. TENSILE TEST RESULTS FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY

Specimen Identification	Ultimate Tensile Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 1 Inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi (GPa)
		78 F (299 K)			
10	133.1 (917.7)	119.0 (820.5)	7.0	12.6	17.0 (117.2)
11	124.3 (857.0)	114.0 (786.0)	6.0	9.9	16.7 (115.1)
12	124.9 (861.2)	114.4 (788.8)	7.0	13.7	17.0 (117.2)
Average	127.4 (878.6)	115.8 (798.4)	6.7	12.1	16.9 (116.5)
		400 F (478 K)			
13	96.6 (666.1)	84.1 (579.9)	7.0	15.6	16.1 (111.0)
14	91.9 (628.1)	78.9 (544.0)	8.0	23.0	15.7 (108.2)
15	100.4 (692.3)	86.7 (597.8)	6.0	9.6	15.2 (104.8)
Average	96.0 (662.1)	83.2 (573.8)	7.0	16.1	15.7 (108.0)
		800 F (700 K)			
16	73.8 (500.8)	58.2 (401.3)	7.5	28.0	13.6 (93.8)
17	78.9 (544.0)	62.3 (429.6)	15.0	30.9	13.6 (93.8)
18	77.2 (532.3)	60.8 (419.2)	10.0	21.1	13.6 (93.8)
Average	76.6 (528.4)	60.4 (416.7)	10.8	26.7	13.6 (93.8)

TABLE 2. COMPRESSION TEST RESULTS FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY

Specimen Identification	0.2 Percent Offset Yield Strength, ksi (MPa)	Compressive Modulus, 10^3 ksi (GPa)
	78 F (299K)	
74	123.2 (849.5)	15.2 (104.8)
75	122.8 (846.7)	16.1 (111.0)
76	125.3 (863.9)	16.3 (112.4)
Average	123.8 (853.4)	15.9 (109.4)
	400 F (478 K)	
77	81.5 (561.9)	15.0 (103.4)
78	84.7 (584.0)	14.9 (102.7)
79	83.7 (577.1)	15.2 (104.8)
Average	83.3 (574.4)	15.0 (103.6)
	800 F (700 K)	
80	62.1 (428.2)	13.5 (93.1)
81	58.2 (401.3)	13.2 (91.0)
82	62.8 (433.0)	12.8 (88.3)
Average	61.0 (420.8)	13.2 (90.8)

TABLE 3. RESULTS OF SHEAR PIN TESTS ON ANNEALED Ti-6Al-4V (CHIP) ALLOY

Specimen Identification	Ultimate Shear Strength, ksi (MPa)
70 F (294 K)	
25	89.8 (619.0)
26	88.3 (609.0)
27	88.3 (608.9)
Average	88.8 (612.3)
400 F (478 K)	
28	70.2 (484.0)
29	72.3 (498.4)
30	71.4 (492.1)
Average	71.3 (491.5)
800 F (700 K)	
31	56.3 (387.9)
32	53.7 (370.1)
33	56.0 (386.2)
Average	55.3 (381.4)

TABLE 4. BEARING TEST RESULTS AT e/D = 1.5 AND e/D = 2.0 FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY

Specimen Identification	Bearing Yield Strength, ksi (MPa)	Bearing Ultimate Strength, ksi (MPa)
	70 F (294 K), e/D = 1.5	
83	201.9 (1391.8)	214.1 (1476.3)
84	211.7 (1459.7)	214.4 (1478.0)
85	206.6 (1424.6)	209.3 (1442.9)
Average	206.7 (1425.4)	212.6 (1465.7)
	400 F (478 K), e/D = 1.5	
86	146.4 (1009.6)	158.3 (1091.6)
87	145.6 (1004.2)	157.5 (1086.1)
88	139.2 (959.8)	147.9 (1019.7)
Average	143.8 (991.2)	154.6 (1065.8)
	800 F (700 K), e/D = 1.5	
89	123.8 (853.7)	154.0 (1061.9)
90	118.4 (816.5)	150.0 (1034.2)
91	119.5 (824.1)	149.3 (1029.2)
Average	120.6 (831.4)	151.1 (1041.8)
	70 F (294 K), e/D = 2.0	
92	245.5 (1692.4)	261.2 (1801.1)
93	242.4 (1671.5)	261.9 (1805.9)
94	251.0 (1730.4)	269.2 (1856.1)
Average	246.28 (1698.1)	264.1 (1821.1)
	400 F (478 K), e/D = 2.0	
95	177.0 (1220.4)	195.5 (1348.2)
96	177.3 (1222.3)	201.6 (1389.7)
97	168.6 (1162.8)	191.1 (1317.7)
98	167.7 (1156.4)	195.2 (1346.2)
99	176.0 (1213.2)	199.0 (1372.1)
100	174.3 (1201.8)	190.0 (1310.3)
Average	173.5 (1196.2)	195.4 (1347.4)
	800 F (700 K), e/D = 2.0	
A	142.1 (980.1)	194.8 (1343.1)
B	142.0 (979.3)	195.6 (1349.0)
C	138.0 (951.6)	187.5 (1292.7)
Average	140.7 (970.3)	192.6 (1328.3)

TABLE 5. FRACTURE TOUGHNESS TEST RESULTS FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY AT ROOM TEMPERATURE

Specimen Identification	Thickness, B, inch (mm)	Width, W inch (mm)	Initial Precrack, inch (mm)	P_Q, lb (kg)	P_{max}, lb (kg)	K_Q, $ksi\sqrt{in}$ ($MPa \cdot mm^{1/2}$)	Valid[a] ?
1	0.7506 (19.06)	1.501 (38.13)	0.6948 (17.65)	3940 (1787)	4050 (1837)	37.09 (40.80)	Yes
2	0.7494 (19.03)	1.498 (38.05)	0.7350 (18.67)	3630 (1647)	3670 (1665)	37.19 (40.91)	Yes
3	0.7511 (19.08)	1.497 (38.02)	0.7254 (18.43)	3570 (16.19)	3620 (1642)	35.85 (39.44)	Yes
						36.71 (40.38)	

[a]Valid K_{Ic} per ASTM E399.

TABLE 6. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED ANNEALED Ti-6Al-4V (CHIP) ALLOY AT A STRESS RATIO OF R = 0.1

Specimen Identification	Maximum Stress, ksi (MPa)	Lifetime, cycles
	74 F (296 K)	
49	120 (827.4)	1,817
52	120 (827.4)	1,270
36	100 (689.5)	22,248
46	100 (689.5)	8,570
37	80 (551.6)	37,560
42	80 (551.6)	35,912
40	60 (413.7)	242,640
53	60 (413.7)	80,675
48	40 (275.8)	15,880,824[a]
	800 F (700 K)	
47	80 (551.6)	128
38	70 (482.6)	13,307
44	70 (482.6)	364
34	60 (413.7)	12,251
39	60 (413.7)	5,484
35	50 (344.7)	72,124
41	50 (344.7)	50,941
43	40 (275.8)	2,045,878
50	40 (275.8)	849,907
45	20 (137.9)	10,001,880[a]

[a]Did not fail; test discontinued.

TABLE 7. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) ANNEALED Ti-6Al-4V (CHIP) ALLOY AT A STRESS RATIO OF R = 0.1

Specimen Identification	Maximum Stress, ksi (MPa)	Lifetime, cycles
	74 F (296 K)	
60	60 (413.7)	9,611
73	60 (413.7)	15,602
57	50 (344.7)	7,320
62	50 (344.7)	12,450
54	40 (295.8)	34,940
59	40 (275.8)	59,050
56	30 (206.8)	180,170
58	30 (206.8)	320,760
65	20 (137.9)	5,139,120
66	20 (137.9)	10,189,840[a]
	800 F (700 K)	
71	55 (379.2)	3,895
68	50 (344.7)	5,280
61	40 (275.8)	11,761
72	40 (275.8)	1,089
55	30 (206.8)	39,816
64	30 (206.8)	32,961
63	20 (137.9)	1,235,757
67	20 (137.9)	316,621
69	15 (103.4)	10,056,714
70	15 (103.4)	8,889,764

[a]Did not fail; test discontinued.

TABLE 8. SUMMARY DATA ON CREEP AND STRESS-RUPTURE PROPERTIES OF ANNEALED Ti-6Al-4V (CHIP) ALLOY AT 800 F (700 K)

Specimen Identification	Stress, ksi (MPa)	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, (50.8 mm), percent	Reduction of Area, percent	Minimum Creep Rate, percent
		0.1	0.2	0.5	1.0	2.0					
19	70 (483)	.13	.26	.84	2.3	6.2	2.703	6.6	4.7	8.5	0.26
22	60 (414)	1.5	5.7	--	--	--	0.555	21.9	0.8	3.6	0.012
20	50 (345)	10.5	40	--	--	--	0.488	68.7	1.6	6.3	0.0025
21	40 (276)	70	450	--	--	--	0.320	2515.0	0.692	--	0.000078
23	35 (241)	65	900	--	--	--	0.295	1962.0	0.551	--	0.000052

TABLE 9. RESULTS OF STRESS-CORROSION-CRACKING TESTS AT ROOM TEMPERATURE FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY

Specimen Identification	Load, lbs (kg)	a, in (mm)	Δa, in (mm)	Δt, sec	da/dt. in/sec $\times 10^{-6}$ (mm/sec $\times 10^{6}$)	K_{Iscc}, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
9	4000 (1814)	0.440 (11.18)	0.002 (0.051)	1800	1.11 (28.2)	24.1 (26.5)
	4250 (1978)	0.443 (11.25)	0.003 (0.076)	1800	1.67 (42.4)	25.7 (28.3)
	4500 (2041)	0.445 (11.30)	0.003 (0.051)	1800	1.11 (28.2)	27.3 (30.0)
	4750 (2154)	0.470 (11.94)	0.025 (0.635)	4140	6.04 (153.4)	30.1 (33.1)
7	1250 (567)	0.608 (15.44)	0.003 (0.076)	83 (hours)	0.01 (0.24)	10.0 (11.0)
	2750 (1247)	0.613 (15.57)	0.005 (0.127)	3600	1.39 (35.3)	22.3 (24.5)
	3000 (1361)	0.617 (15.67)	0.004 (0.102)	3600	1.11 (28.2)	24.5 (26.9)
	3250 (1474)	0.625 (15.88)	0.008 (0.203)	1800	4.44 (112.8)	26.9 (29.6)
	3500 (1587)	0.632 (16.05)	0.007 (0.178)	17 (hours)	0.11 (3.9)	29.4 (32.3)
8	2000 (907)	0.534 (13.56)	0.001 (0.025)	1800	0.56 (14.12)	14.1 (15.5)
	2125 (964)	0.536 (13.61)	0.002 (0.051)	1800	1.11 (28.2)	15.1 (16.6)
	2250 (1020)	0.539 (13.69)	0.003 (0.076)	1800	1.67 (42.4)	16.0 (17.6)
	2500 (1134)	0.540 (13.72)	0.001 (0.025)	1800	0.56 (14.12)	17.9 (14.7)
	3500 (1587)	0.562 (14.27)	0.022 (0.559)	15 (hours)	0.41 (10.34)	26.0 (28.6)
	3850 (1746)	0.600 (15.24)	0.038 (0.965)	72 (hours)	0.15 (37.3)	30.5 (33.6)

TABLE 10. FATIGUE-CRACK-PROPAGATION DATA FOR ANNEALED Ti-6Al-4V (CHIP) ALLOY

a, inch (mm)	N, cycles x 10^3	3-pt da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		DS-4	
.5620 (14.27)	1.0	1.009E-06 (2.564E-05)	8.35 (9.18)
.5740 (14.58)	10.0	1.009E-06 (2.564E-05)	8.53 (9.37)
.5810 (14.76)	25.5	5.174E-07 (1.314E-05)	8.63 (9.48)
.5860 (14.88)	34.5	5.629E-07 (1.430E-05)	8.71 (9.57)
.5989 (15.10)	55.2	4.105E-07 (1.043E-05)	8.89 (9.77)
.6030 (15.32)	76.0	2.422E-07 (6.151E-06)	8.97 (9.86)
.6080 (15.44)	96.5	2.889E-07 (7.337E-06)	9.05 (9.95)
.6160 (15.65)	120.0	3.367E-07 (8.552E-06)	9.18 (10.09)
.6230 (15.82)	141.0	4.020E-07 (1.821E-05)	9.30 (10.22)
.6380 (16.20)	171.0	1.487E-07 (3.777E-06)	9.55 (10.50)
.6380 (16.20)	183.7	1.754E-07 (4.454E-06)	9.55 (10.50)
.6480 (16.46)	205.0	4.529E-07 (1.150E-05)	9.73 (10.69)
.6570 (16.69)	225.6	6.030E-07 (1.532E-05)	9.89 (10.87)
.6850 (17.40)	258.0	7.402E-07 (1.880E-05)	10.42 (11.45)
.7000 (17.78)	281.0	7.850E-07 (1.994E-05)	10.72 (11.78)
.7170 (18.21)	300.0	1.029E-06 (2.614E-05)	11.09 (12.18)
.7280 (18.49)	310.0	1.129E-06 (2.867E-05)	11.33 (12.45)
.7410 (18.82)	321.2		11.63 (12.78)
		DS-5	
.5576 (14.16)	0.0		8.28 (9.10)
.5687 (14.44)	30.2	4.369E-07 (1.110E-05)	8.44 (9.27)
.5840 (14.83)	60.4	5.994E-07 (1.522E-05)	8.67 (9.52)
.6049 (15.36)	90.6	9.367E-07 (2.379E-05)	8.99 (9.88)
.6364 (16.16)	117.8	1.411E-06 (3.584E-05)	9.51 (10.45)
.6765 (17.18)	142.3	2.166E-06 (5.502E-05)	10.24 (11.26)
.7348 (18.66)	164.3	3.534E-06 (8.976E-05)	11.47 (12.60)
.8209 (20.85)	184.2	5.664E-06 (1.439E-04)	13.79 (15.15)
.9435 (23.96)	202.1		18.82 (20.68)
		DS-6	
.5050 (12.83)	0.0		7.57 (8.31)
.5067 (12.87)	20.1	1.433E-07 (3.639E-06)	7.59 (8.34)
.5108 (12.97)	40.3	2.041E-07 (5.185E-06)	7.64 (8.40)
.5149 (13.08)	60.4	2.968E-07 (7.538E-06)	7.69 (8.45)

TABLE 10. (Concluded)

a, inch (mm)	N, cycles x 10^3	3-pt da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		DS-6 (Continued)	
.5227 (13.28)	80.6	4.041E-07 (1.027E-05)	7.80 (8.57)
.5312 (13.49)	100.8	5.145E-07 (1.307E-05)	7.91 (8.69)
.5435 (13.80)	120.9	6.306E-07 (1.602E-05)	8.08 (8.88)
.5566 (14.14)	141.1	9.381E-07 (2.383E-05)	8.27 (9.08)
.5813 (14.76)	161.3	1.288E-06 (3.271E-05)	8.63 (9.48)
.6057 (15.38)	179.4	1.404E-06 (3.566E-05)	9.00 (9.89)
.6295 (15.99)	195.7	1.745E-06 (4.432E-05)	9.39 (10.32)
.6590 (16.74)	210.4	2.256E-06 (5.731E-05)	9.91 (10.89)
.6918 (17.57)	223.7	2.950E-06 (7.493E-05)	10.54 (11.59)
.7320 (18.59)	235.6	3.466E-06 (8.803E-05)	11.41 (12.53)
.7703 (19.57)	246.4	4.022E-06 (1.022E-04)	12.34 (13.56)
.8134 (20.65)	256.1	4.892E-06 (1.243E-04)	13.56 (14.89)
.8596 (21.83)	264.8	6.409E-06 (1.628E-04)	15.10 (16.60)
.9182 (23.32)	272.7	9.957E-06 (2.529E-04)	17.55 (19.29)
1.0057 (25.54)	279.8		22.72 (24.97)

Specimen Identification	Thickness, B, inch (mm)	Width, W, inch (mm)
DS-4	0.7507 (19.06)	1.500 (38.10)
DS-5	0.7520 (19.10)	1.499 (38.07)
DS-6	0.7510 (19.08)	1.497 (38.02)

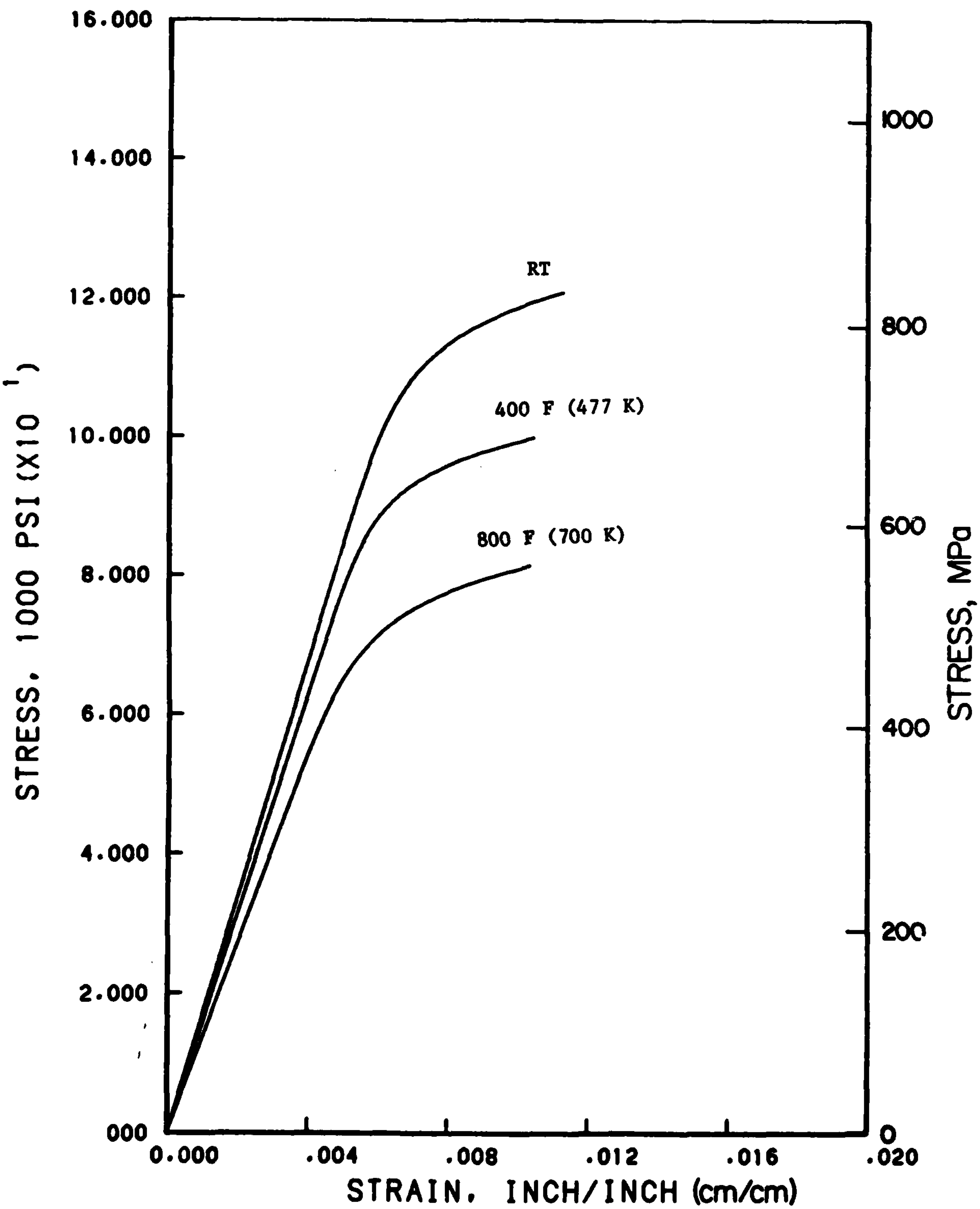


Figure 1. Typical tensile stress-strain curves for annealed Ti-6Al-4V (CHIP) alloy.

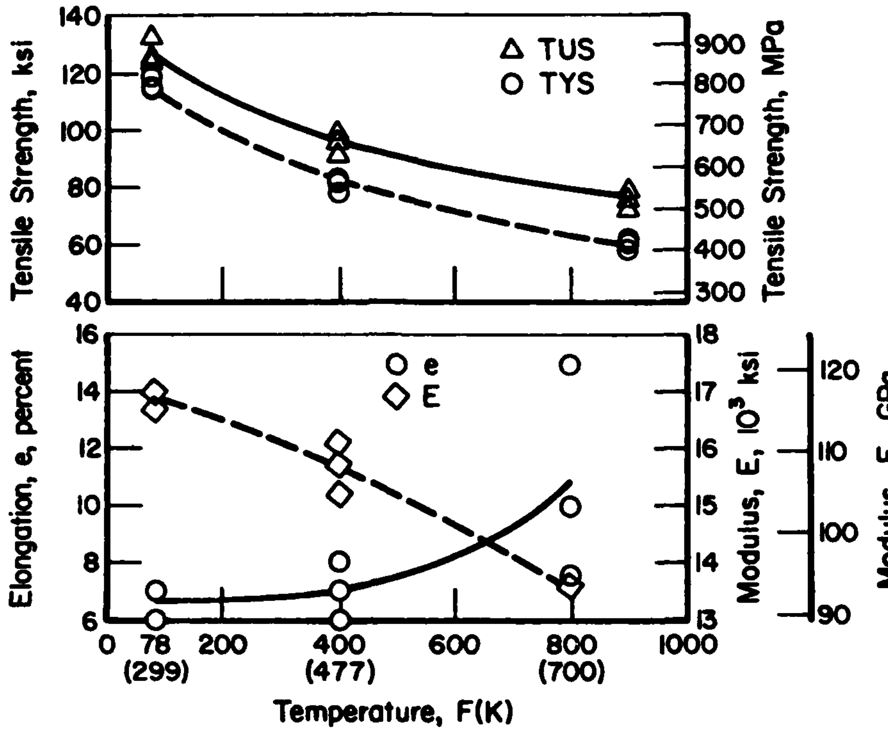


Figure 2. Effect of temperature on the tensile properties of annealed Ti-6Al-4V (CHIP) alloy.

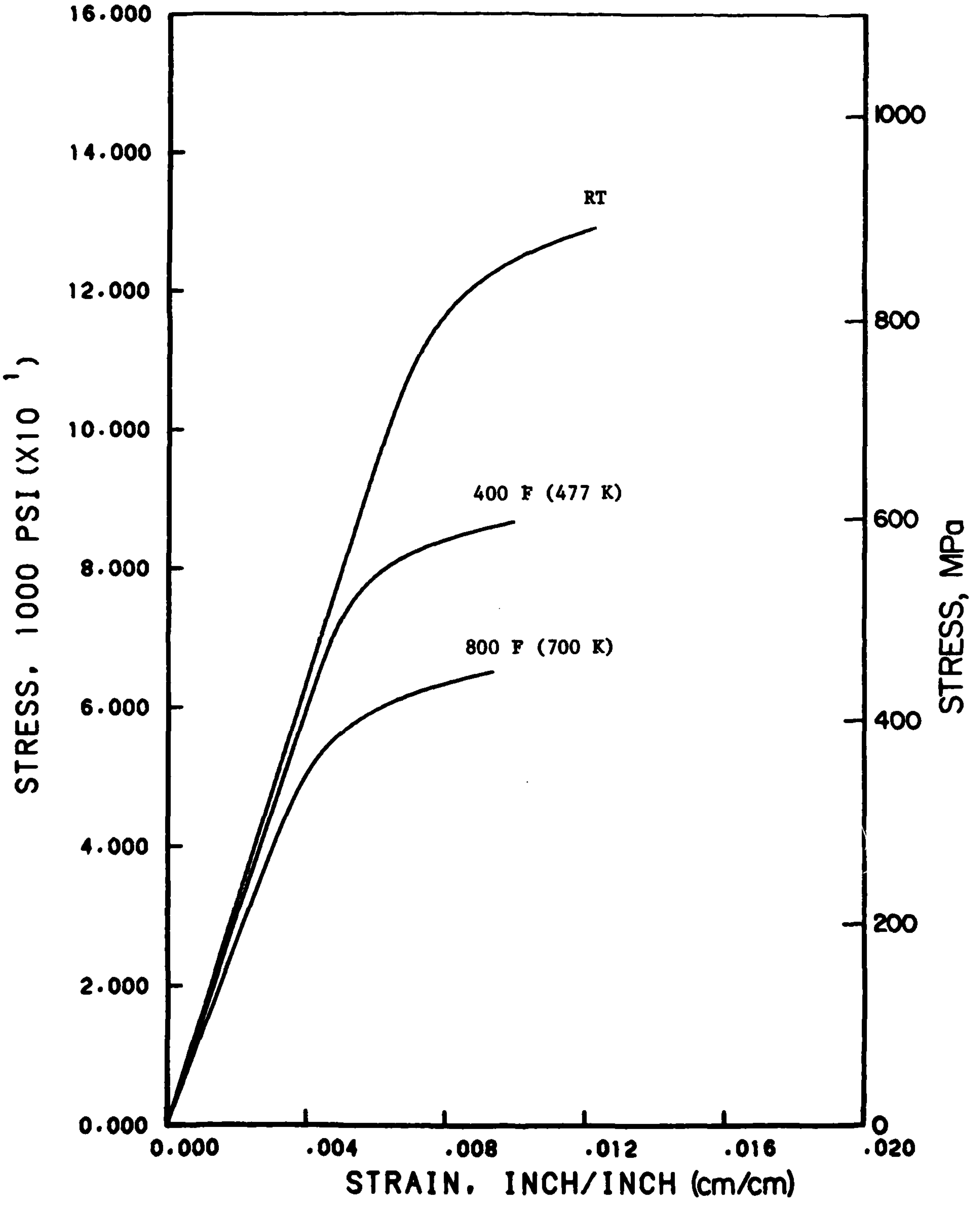


Figure 3. Typical compressive stress-strain curves for annealed Ti-6Al-4V (CHIP) alloy.

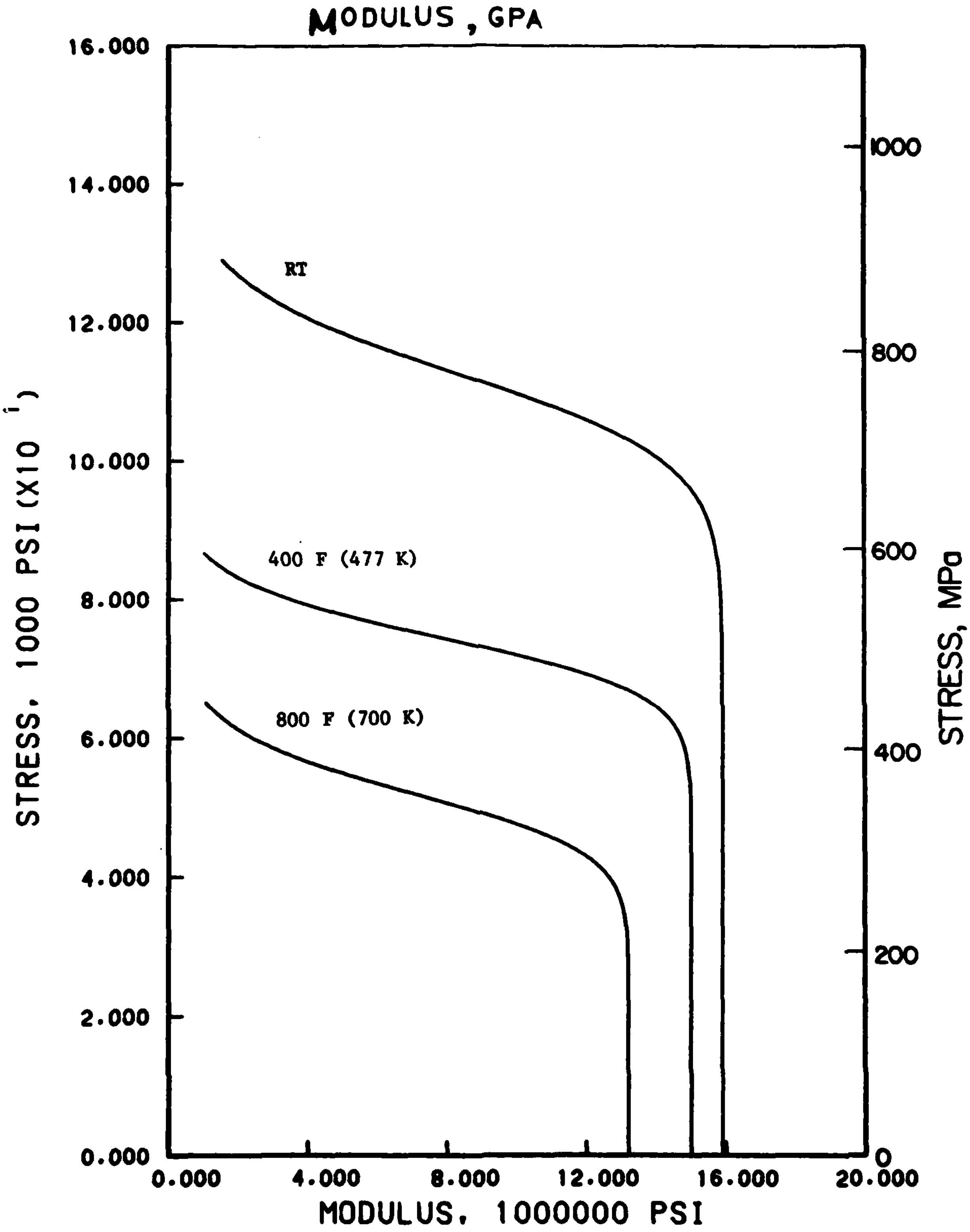


Figure 4. Typical compressive tangent-modulus curves for annealed Ti-6Al-4V (CHIP) alloy.

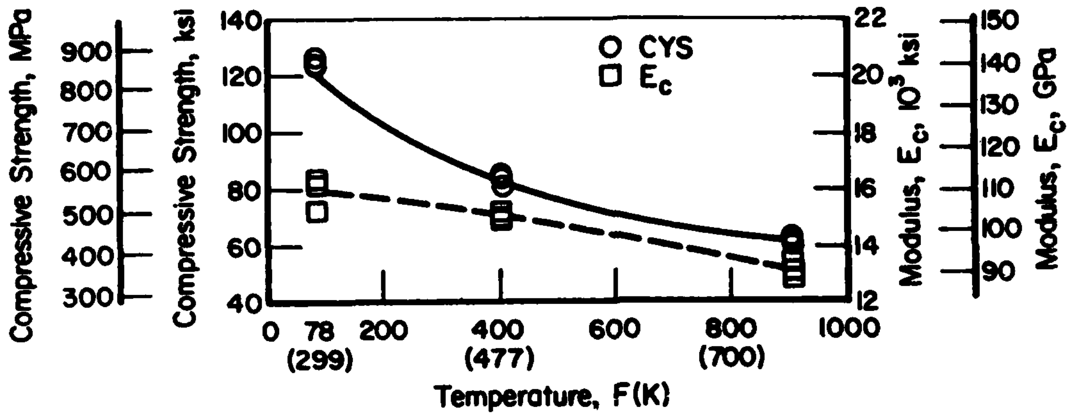


Figure 5. Effect of temperature on the compressive properties of annealed Ti-6Al-4V (CHIP) alloy.

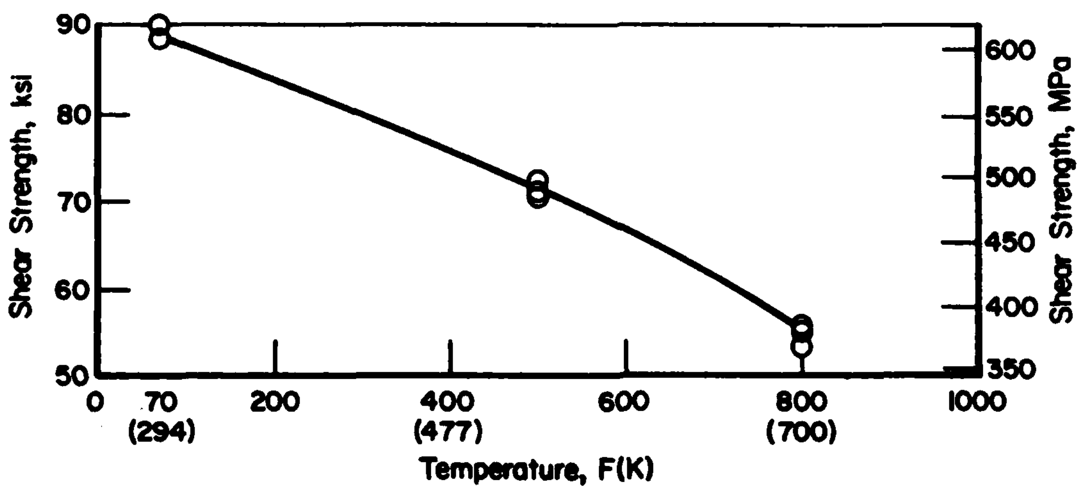


Figure 6. Effect of temperature on the pin shear properties of annealed Ti-6Al-4V (CHIP) alloy.

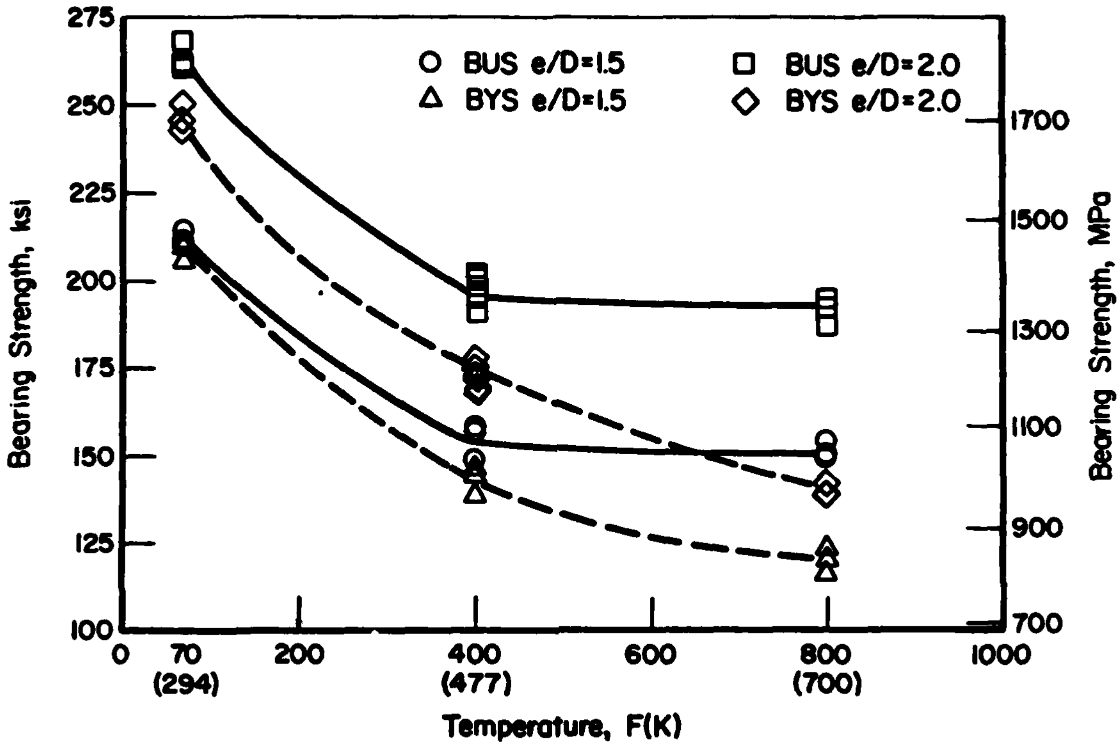


Figure 7. Effect of temperature on the bearing properties of annealed Ti-6Al-4V (CHIP) alloy.

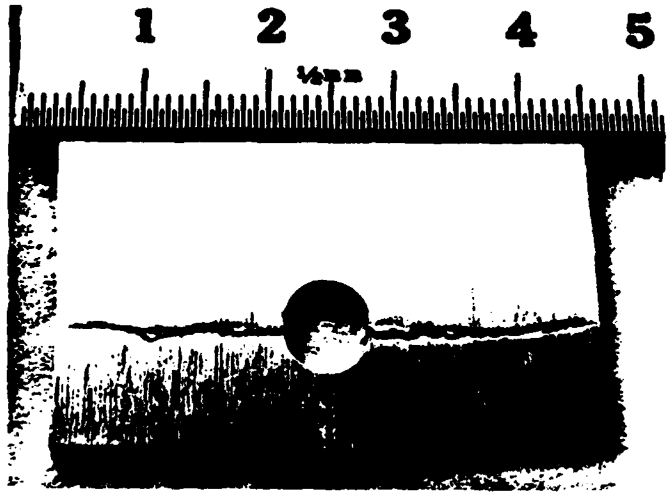


Figure 8. Typical bearing test specimen for annealed Ti-6Al-4V (CHIP) alloy after testing (e/D = 1.5).

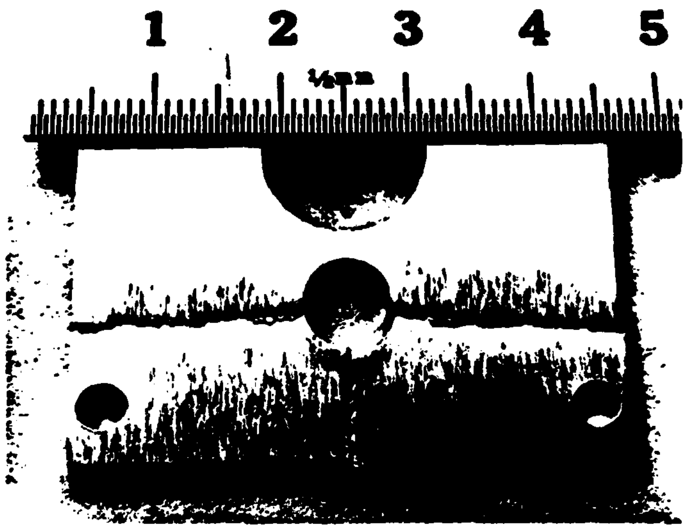


Figure 9. Typical bearing test specimen for annealed Ti-6Al-4V (CHIP) alloy after testing (e/D = 2.0).

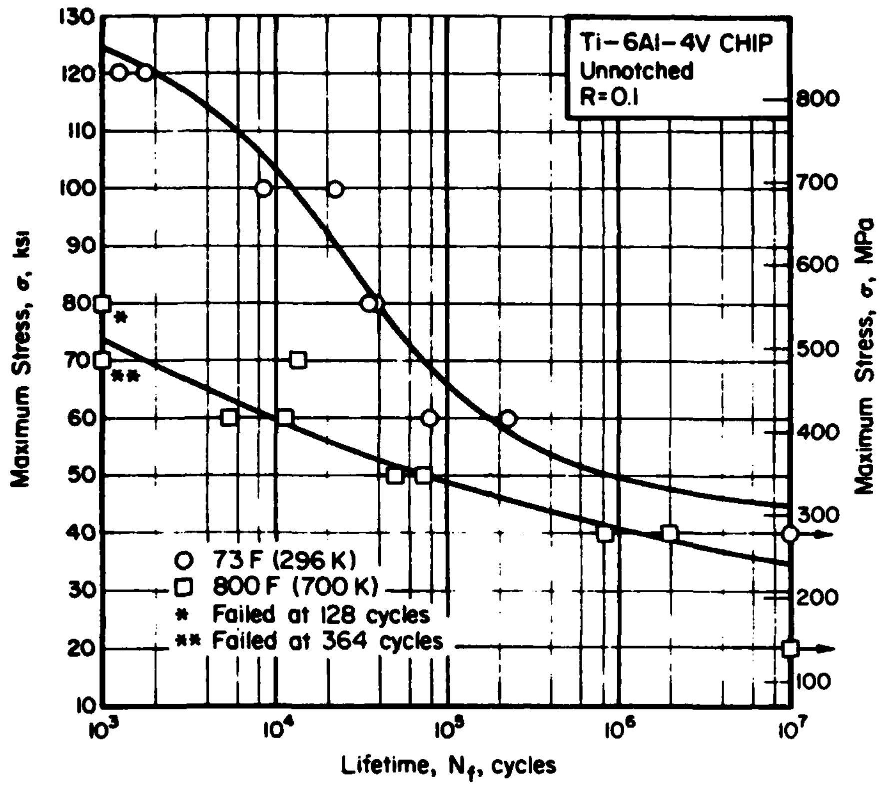


Figure 10. Axial load fatigue behavior of unnotched, annealed Ti-6Al-4V (CHIP) alloy.

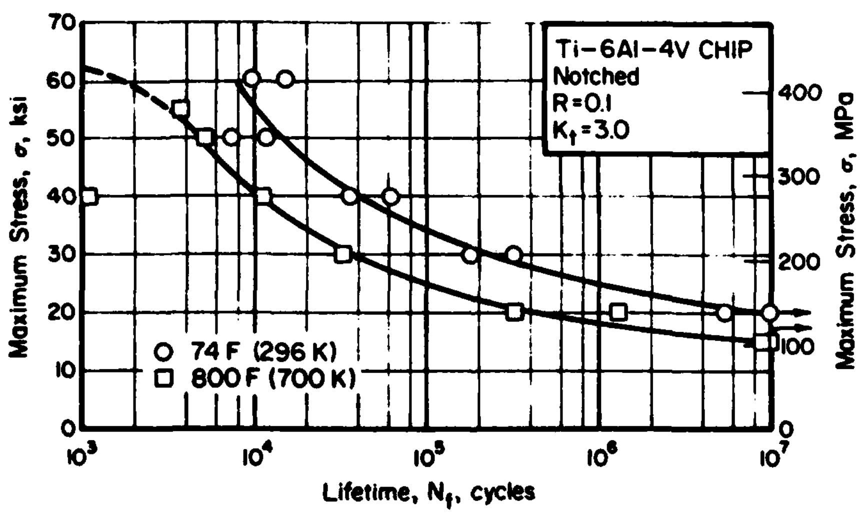


Figure 11. Axial load fatigue behavior of notched (K_t = 3.0), annealed Ti-6Al-4V (CHIP) alloy.

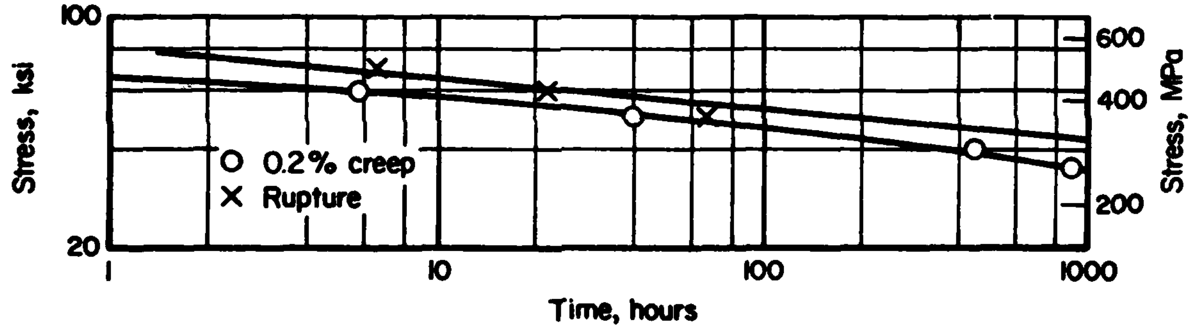


Figure 12. Stress-rupture and plastic deformation curves for annealed Ti-6Al-4V (CHIP) alloy.

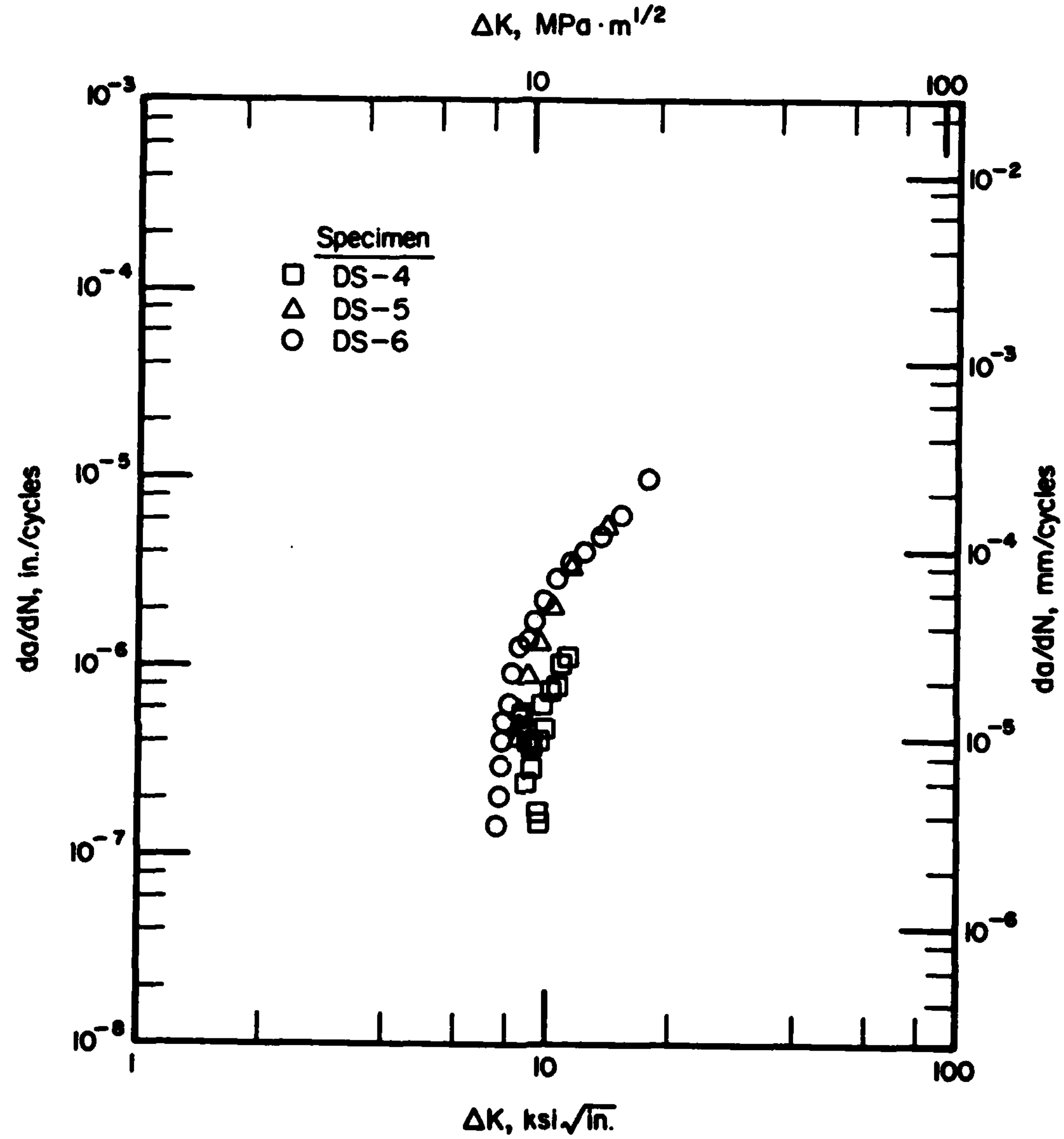


Figure 13. Plot of da/dN versus delta K for annealed Ti-6Al-4V (CHIP) alloy.

Lab Air
R = 0.1
Frequency = 20 Hz

CT-91-T7E69 Aluminum

Material Description

CT-91-T7E69 aluminum alloy is a powder metallurgy product of Alcoa. The material was received as two 1½-inch (38.1 mm) thick x 4½-inch (114 mm) wide x 4-foot (1.22 m) extrusions.

The chemical composition of this lot is as follows:

Chemical Composition	Percent Weight
Silicon	0.15
Iron	0.20
Copper	1.20 - 2.00
Magnesium	2.20 - 3.00
Zinc	6.00 - 7.00
Cobalt	0.20 - 0.60
Other	0.15
Aluminum	Balance.

Processing and Heat Treating

The CT-91 aluminum was received in the T7E69 condition. This temper was designed to have good static strength and fatigue resistance.

Test Results

Results of these tests show higher tensile, shear, and fatigue data as compared to the T7E70 temper while giving lower fracture toughness values.

A specimen layout is shown in Figure 14.

Tension. Tests were conducted at room temperature, 250 F (394 K), and 350 F (450 K). The test results are shown in Table 11. Typical stress-strain curves at temperature for longitudinal and long transverse specimens are shown in Figures 15 and 16. Effect-of-temperature curves are presented in Figure 17.

Compression. Tests were conducted at room temperature, 250 F (394 K), and 350 F (450 K). The results are presented in Table 12. Typical stress-strain and tangent-modulus curves for longitudinal and long transverse

specimens are shown in Figures 18, 19, 20, and 21. Effect-of-temperature curves are shown in Figure 22.

<u>Shear</u>. Tests were conducted at 77 F (298 K), 250 F (394 K), and 350 F (450 K) in both the longitudinal and long transverse directions. Results are shown in Table 13. Effect-of-temperature curves are shown in Figure 23.

<u>Bearing</u>. Tests were conducted at 72 F (295 K), 250 F (394 K), and 350 F (450 K) in both the longitudinal and long transverse directions for e/D = 1.5 and e/D = 2.0. Test results are given in Table 14. Figure 24 shows the effect-of-temperature curves.

<u>Fracture Toughness</u>. Table 15 shows the test results at 70 F (294 K) for L-T and T-L specimens. The calculated K_Q values shown are valid K_{Ic} values per ASTM E399.

<u>Fatigue</u>. Axial-load-fatigue test results on unnotched and notched (K_t = 3.0) specimens at room temperature and 350 F (450 K) are presented in Tables 16 and 17. The S-N curves are shown in Figures 25 and 26.

<u>Stress-Corrosion Cracking</u>. Increasing K tests at 74 F (296 K) were conducted. A value of 3 ksi$\sqrt{in}$ (3.3 MPa$\sqrt{m}$) for K_{Iscc} at 10^{-8} in/sec (25.4×10^{-8} mm/sec) was determined as a best approximation. Results are given in Table 18.

<u>Crack Growth</u>. Test results for the compact-tension, fatigue-crack-propagation specimens are given in Table 19. Figure 27 shows da/dN versus delta K.

<u>Thermal Expansion</u>. The coefficient of thermal expansion is 13.1×10^{-6} in/in-F (68 - 212 F) [23.6×10^{-6} m/m-K (293 - 373 K)], which is a calculated value supplied by Alcoa.

<u>Density</u>. The density is 0.102 lb/in^3 (2.823 g/cc) as supplied by Alcoa.

TABLE 11. TENSILE TEST RESULTS FOR CT-91-T7E69 ALUMINUM EXTRUSION

Specimen Identi- fication	Ultimate Tensile Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 2 Inches (50.8 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi (GPa)
		78 F (299 K), Longitudinal			
L-1	90.1 (621.2)	83.3 (574.4)	11.0	28.0	11.2 (77.2)
L-2	88.9 (613.0)	82.5 (568.8)	11.0	30.0	10.7 (73.8)
L-3	89.9 (619.9)	83.2 (573.7)	11.0	28.8	10.5 (72.4)
Average	89.6 (618.0)	83.0 (572.3)	11.0	28.9	10.0 (74.5)
		78 F (299 K), Long Transverse			
T-10	83.5 (575.7)	75.2 (518.5)	11.0	26.6	10.6 (73.1)
T-11	83.7 (577.1)	75.0 (517.1)	12.0	27.4	11.4 (78.6)
T-12	83.5 (575.7)	74.6 (514.4)	12.0	33.0	10.5 (72.4)
Average	83.6 (576.2)	74.9 (516.7)	11.7	29.0	10.8 (74.7)
		250 F (394 K), Longitudinal			
L-4	73.8 (508.8)	72.2 (497.8)	19.0	50.5	10.0 (68.6)
L-5	75.4 (519.9)	74.0 (510.8)	18.5	51.1	9.5 (65.6)
L-6	74.3 (512.5)	72.5 (499.9)	18.5	49.2	9.8 (67.9)
Average	74.5 (513.8)	72.9 (502.8)	18.7	50.3	9.8 (67.4)
		250 F (394 K), Long Transverse			
T-13	69.3 (477.7)	65.5 (451.6)	17.0	42.5	9.2 (63.4)
T-14	70.7 (487.3)	67.4 (464.7)	17.5	38.7	9.5 (65.7)
T-15	69.5 (479.2)	65.4 (450.9)	17.0	42.7	9.7 (67.2)
Average	69.8 (481.4)	66.1 (455.8)	17.2	41.3	9.5 (65.4)
		350 F (450 K), Longitudinal			
L-7	59.2 (408.6)	57.8 (398.4)	22.5	61.5	9.5 (65.3)
L-8	58.3 (401.8)	56.7 (391.2)	23.0	63.1	9.2 (63.6)
L-9	60.0 (413.5)	57.9 (399.1)	22.5	64.2	9.1 (62.5)
Average	59.2 (408.0)	57.5 (396.2)	22.7	62.9	9.2 (63.8)
		350 F (450 K), Long Transverse			
T-16	54.8 (378.1)	52.7 (363.3)	21.0	51.1	8.5 (58.5)
T-17	54.2 (373.6)	51.2 (352.9)	20.0	48.5	9.5 (65.5)
T-18	55.6 (383.6)	52.7 (363.4)	23.5	56.6	9.0 (62.2)
Average	54.9 (378.4)	52.2 (359.9)	21.5	52.1	9.0 (62.1)

TABLE 12. COMPRESSIVE TEST RESULTS FOR CT-91-
T7E69 ALUMINUM EXTRUSION

Specimen Identi-fication	0.2 Percent Offset Yield Strength, ksi (MPa)	Compressive Modulus, 10^3 ksi (GPa)
	78 F (299 K), Longitudinal	
L-19	83.8 (577.8)	11.0 (75.9)
L-20	80.8 (557.1)	10.4 (71.7)
L-21	84.7 (584.0)	10.3 (71.0)
Average	83.1 (573.0)	10.6 (72.9)
	78 F (299 K), Long Transverse	
T-28	80.9 (557.8)	10.5 (72.4)
T-29	80.7 (556.4)	9.8 (67.6)
T-30	80.7 (556.4)	9.8 (67.6)
Average	80.77 (556.9)	10.0 (69.2)
	250 F (394 K), Longitudinal	
L-22	75.1 (517.8)	9.2 (63.43)
L-23	75.4 (519.9)	8.9 (61.4)
L-24	75.5 (520.6)	9.7 (66.9)
Average	75.3 (519.4)	9.3 (63.9)
	250 F (394 K), Long Transverse	
T-31	71.8 (495.1)	10.0 (69.0
T-32	72.3 (498.5)	9.6 (66.2)
T-33	71.8 (495.1)	9.7 (66.9)
Average	72.0 (496.2)	9.8 (67.3)
	350 F (450 K), Longitudinal	
L-25	56.7 (391.0)	8.6 (59.3)
L-26	58.7 (404.7)	9.0 (62.1)
L-27	55.7 (384.1)	8.5 (58.6)
Average	57.0 (393.2)	8.7 (60.0)
	350 F (450 K), Long Transverse	
T-34	56.0 (386.1)	7.8 (53.8)
T-35	56.7 (391.0)	8.9 (61.4)
T-36	58.2 (401.3)	8.8 (60.7)
Average	57.0 (392.8)	8.5 (58.6)

TABLE 13. RESULTS OF PIN SHEAR TESTS ON CT-91-T7E69 ALUMINUM EXTRUSION

Specimen Identification	Longitudinal Ultimate Shear Strength, ksi (MPa)	Specimen Identification	Long Transverse Ultimate Shear Strength, ksi (MPa)
	77 F (298 K)		
L-37	52.3 (360.3)	T-46	50.7 (349.7)
L-38	53.5 (368.6)	T-47	49.0 (337.7)
L-39	52.6 (362.8)	T-49	49.6 (342.1)
Average	52.8 (363.9)	Average	49.8 (343.1)
	250 F (394 K)		
L-40	44.0 (303.2)	T-49	43.9 (302.6)
L-41	44.8 (309.2)	T-50	44.0 (303.3)
L-42	44.9 (309.5)	T-61	43.2 (298.1)
Average	44.6 (307.3)	Average	43.7 (301.4)
	350 F (450 K)		
L-43	34.3 (236.2)	T-52	31.9 (220.1)
L-44	35.3 (243.7)	T-53	33.8 (233.0)
L-45	36.3 (250.4)	T-54	33.5 (231.0)
Average	35.3 (243.4)	Average	33.1 (228.0)

TABLE 14. BEARING TEST RESULTS AT e/D = 1.5 AND e/D = 2.0
FOR CT-91-T7E69 ALUMINUM EXTRUSION

e/D = 1.5						e/D = 2.0					
Specimen Identi-fication	Bearing Yield Strength, ksi	(MPa)	Bearing Ultimate Strength, ksi	(MPa)		Specimen Identi-fication	Bearing Yield Strength, ksi	(MPa)	Bearing Ultimate Strength, ksi	(MPa)	
72 F (295 K), Longitudinal											
L-55	106.0	(730.6)	133.0	(917.3)		L-64	126.2	(870.3)	172.9	(1192.4)	
L-56	100.7	(749.4)	136.5	(941.4)		L-65	125.5	(865.3)	173.2	(1193.9)	
L-57	108.2	(746.0)	135.8	(936.0)		L-66	126.2	(870.3)	169.5	(1168.7)	
Average	107.6	(742.0)	135.1	(931.6)		Average	126.0	(688.6)	171.9	(1185.0)	
72 F (295 K), Long Transverse											
T-73	107.9	(744.0)	134.6	(927.9)		T-82	125.5	(865.0)	168.0	(1158.4)	
T-74	110.8	(763.8)	0.0	(0.0)		T-83	125.3	(863.6)	172.1	(1186.9)	
T-75	105.3	(726.1)	126.9	(874.6)		T-84	132.4	(913.2)	171.7	(1183.7)	
Average	108.0	(744.6)	130.7	(901.3)		Average	127.7	(880.6)	170.6	(1176.3)	
250 F (394 K), Longitudinal											
L-58	94.7	(653.0)	111.3	(767.1)		L-67	105.0	(724.3)	141.1	(973.0)	
L-59	97.8	(674.3)	112.1	(772.7)		L-68	115.1	(793.3)	148.1	(1021.3)	
L-60	95.3	(657.3)	109.8	(757.1)		L-69	115.3	(795.3)	147.6	(1018.0)	
Average	96.0	(661.6)	111.0	(765.6)		Average	111.0	(770.9)	145.6	(1004.1)	
250 F (394 K), Long Transverse											
T-76	96.9	(668.0)	110.5	(761.8)		T-85	113.7	(784.0)	146.0	(1006.9)	
T-77	96.4	(664.7)	111.1	(766.2)		T-86	111.3	(767.3)	147.7	(1018.5)	
T-78	99.0	(682.8)	113.3	(781.3)		T-87	111.2	(766.7)	146.6	(1011.0)	
Average	97.4	(671.8)	111.6	(769.8)		Average	112.1	(772.7)	146.8	(1012.1)	
350 F (450 K), Longitudinal											
L-61	77.8	(536.4)	84.7	(583.9)		L-70	90.8	(626.2)	108.7	(749.8)	
L-62	77.6	(535.[illegible])	86.1	(593.6)		L-71	86.4	(595.4)	108.2	(745.8)	
L-63	78.9	(543.8)	87.2	(601.5)		L-72	90.2	(621.6)	107.9	(744.3)	
Average	78.1	(538.4)	86.0	(593.0)		Average	89.1	(614.4)	108.3	(746.6)	
350 F (450 K), Long Transverse											
T-79	78.5	(540.9)	85.3	(588.1)		T-88	91.2	(628.6)	107.8	(743.4)	
T-80	73.5	(506.6)	80.3	(553.7)		T-89	90.0	(620.7)	111.5	(768.5)	
T-81	78.5	(540.9)	85.5	(589.3)		T-90	88.4	(609.5)	107.4	(740.6)	
Average	76.8	(529.5)	83.7	(577.0)		Average	89.9	(619.6)	108.9	(750.8)	

TABLE 15. FRACTURE TOUGHNESS TEST RESULTS FOR CT-91-T7E69 ALUMINUM EXTRUSION AT ROOM TEMPERATURE

Specimen Identification	Thickness, B, inch (mm)	Width, W, inch (mm)	Initial Precrack, inch (mm)	P_Q, lbs (kg)	K_a, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)	Valid[a] ?
			Longitudinal			
L-91	1.485 (37.72)	3.022 (76.76)	1.4985 (38.06)	6600 (2994)	24.38 (26.82)	Yes
L-92	1.484 (37.69)	3.019 (76.68)	1.511 (38.38)	6440 (2921)	24.16 (26.58)	Yes
L-93	1.486 (37.74)	3.014 (76.56)	1.504 (38.20)	6450 (2926)	24.07 (26.48)	Yes
					24.20 (26.62)	
			Long Transverse			
T-94	1.485 (37.72)	3.013 (76.53)	1.496 (38.00)	9587 (4348)	35.54 (39.09)	Yes
T-95	1.490 (37.85)	3.014 (76.56)	1.505 (38.23)	9875 (4479)	36.80 (40.48)	Yes
T-96	1.485 (37.72)	3.020 (76.71)	1.518 (38.56)	8912 (4042)	33.07 (36.38)	Yes
					35.14 (38.65)	

[a]Valid K_{Ic} as per ASTM E399.

TABLE 16. AXIAL LOAD UNNOTCHED FATIGUE TEST RESULTS FOR CT-91-T7E69 ALUMINUM EXTRUSION - LONG TRANSVERSE

Specimen Identification	Maximum Stress, ksi (MPa)	Cycles to Failure
	74 F (296 K)	
105U	76.75 (529.2)	13,960[a]
110U	71.27 (491.4)	23,170
101U[b]	70 (482.6)	60.020[c]
109U	65.79 (453.6)	29,360
115U	65.79 (453.6)	22,550[d]
104U[b]	65 (448.2)	67,740
113U	60.31 (415.8)	2,185,570
117U[b]	60 (413.7)	78,470[e]
106U	60 (413.7)	5,239,970
112U[b]	55 (479.2)	17,830
105U	54.82 (378.0)	13,511,680[f]
103U[b]	50 (344.8)	372,850[g]
102U[b]	50 (344.8)	985,150[g]
115U	49.34 (340.2)	17,979,840[f]
117U	35 (241.3)	14,342,020[f]
	350 F (450 K)	
107U	55 (479.2)	1,200
114U	50 (344.8)	64,000
116U	45 (310.3)	88,820
108U	40 (275.8)	229,870
119U	35 (241.3)	461,970
118U	30 (206.8)	4,373,020

[a]Rerun of 54.82 ksi (378.).

[b]0.250" (6.35 mm) diameter specimen.

[c]Failed in shoulder.

[d]Rerun of 49.34 ksi (340.2).

[e]Rerun of 35 ksi (241.3).

[f]Did not fail.

[g]Failed in grips.

TABLE 17. AXIAL LOAD, NOTCHED (K_t = 3.0) FATIGUE TEST RESULTS FOR CT-91-T7E69 ALUMINUM EXTRUSION - LONG TRANSVERSE

Specimen Identification	Maximum Stress, ksi (MPa)	Cycles to Failure
	74 F (296 K)	
122	50 (344.8)	3,010
127	40 (275.8)	9,120
121	30 (206.8)	22,680
120	30 (206.8)	30,050
123	25 (172.4)	69,190
124	25 (172.4)	74,950
128	22.5 (155.1)	232,720
133	22.5 (155.1)	966,100
134	20 (137.9)	12,982,000[a]
125	20 (137.9)	13,100,000[a]
	350 F (450 K)	
131	45 (310.3)	940[b]
132	40 (275.8)	3,410
134	35 (241.3)	5,360[c]
135	25 (172.4)	21,270
126	20 (137.9)	67,670
139	20 (137.9)	74,370
136	17.5 (120.7)	134,990
130	15 (103.4)	196,610
137	15 (103.4)	227,530
138	12.5 (86.2)	217,350[d]
129[e]	12.5 (86.2)	2,966,350
138	10 (68.9)	10,399,470[a]
131	10 (68.9)	12,835,800[a]

[a]Did not fail.

[b]Rerun of 10 ksi (68.9) 350 F (450 K).

[c]Rerun of 20 ksi (137.9) 74 F (296 K).

[d]Rerun of 10 ksi (68.9) 350 F (450 K).

[e]Stopped and restarted.

TABLE 18. RESULTS OF THE STRESS-CORROSION-CRACKING TESTS AT ROOM TEMPERATURE FOR CT-91-T7E69 ALUMINUM EXTRUSION L-T SPECIMENS

Specimen Identification	Load, lbs	(kg)	a, in	(mm)	Δa, in	(mm)	Δt, sec	da/dt, in/sec x 10^{-6}	(mm/sec x 10^{-6})	K_{Iscc}, ksi$\sqrt{in}$	(MPa$\sqrt{m}$)
T-95R	185	(83.9)	1.8087	(45.94)	0.0047	(0.119)	3600	1.3	(33.0)	0.98	(1.08)
	230	(104.3)	1.8133	(46.06)	0.0046	(0.117)	3600	1.3	(33.0)	1.22	(1.34)
	280	(127.0)	1.8155	(46.11)	0.0022	(0.056)	3600	0.6	(15.2)	1.49	(1.64)
	325	(147.4)	1.8176	(46.17)	0.0031	(0.053)	3600	0.6	(15.2)	1.74	(1.91)
	370	(167.8)	1.8198	(46.22)	0.0022	(0.056)	7200	0.3	(7.6)	1.98	(2.18)
	460	(208.6)	1.822	(46.28)	0.0022	(0.056)	3600	0.6	(15.2)	2.47	(2.72)
	555	(251.7)	1.8252	(46.36)	0.0032	(0.081)	10800	0.3	(7.6)	3.00	(3.30)
	740	(335.6)	1.832	(46.53)	0.0068	(0.173)	3600	1.9	(48.3)	4.03	(4.43)
	830	(376.5)	1.8328	(46.55)	0.0008	(0.020)	2700	0.3	(7.6)	4.53	(4.98)
T-97R	185	(83.9)	1.8342	(46.59)	0.0014	(0.036)	1800	0.78	(19.8)	1.01	(1.11)
	370	(167.8)	1.8362	(46.64)	0.002	(0.051)	3600	0.56	(14.2)	2.03	(2.23)
	460	(208.6)	1.8382	(46.69)	0.002	(0.051)	3600	0.56	(14.2)	2.53	(2.78)
	555	(251.7)	1.8402	(46.74)	0.002	(0.051)	7200	0.28	(7.1)	3.06	(3.37)
	650	(294.8)	1.84218	(46.79)	0.00198	(0.050)	9000	0.22	(5.6)	3.59	(3.95)
	740	(335.6)	1.84318	(46.82)	0.001	(0.025)	3600	0.28	(7.1)	4.09	(4.50)
	820	(371.9)	1.84398	(46.84)	0.0008	(0.020)	15 hours	0.016	(0.4)	4.54	(4.99)
T-99R*	3535	(1603)	1.8664	(47.41)	0.0004	(0.010)	3600	0.1	(2.5)	20.17	(22.19)
	3700	(1678)	1.8668	(47.42)	0.0002	(0.005)	1800	0.1	(2.5)	21.13	(23.24)
	4620	(2096)	1.867	(47.42)	0.0002	(0.005)	1800	0.1	(2.5)	26.39	(29.03)
	5085	(2306)	1.8672	(47.43)	0.0002	(0.005)	1800	0.1	(2.5)	29.05	(31.96)
	5545	(2515)	1.8674	(47.43)	0.0002	(0.005)	1800	0.1	(2.5)	31.69	(34.86)
	6010	(2726)	1.8677	(47.44)	0.0003	(0.008)	2700	0.1	(2.5)	34.36	(37.80)
	6470	(2935)	1.8697	(47.49)	0.002	(0.051)	3600	0.56	(14.2)	37.09	(40.80)
	6930	(3143)	1.8703	(47.51)	0.0006	(0.015)	1800	0.35	(8.9)	39.76	(43.74)

*Crack front was atypical for this type specimen.

TABLE 19. FATIGUE-CRACK-PROPAGATION DATA FOR CT-91-T7E69 ALUMINUM EXTRUSION, L-T SPECIMENS

a, inches (mm)	N, cycles x 10^3	da/dN, in/cycle (mm/cycle)	ΔK, ksi√in (MPa√m)
		T-97	
1.6434 (41.74)	0.0		2.67 (2.94)
1.6463 (41.82)	25.1	1.127E-07 (2.863E-06)	2.68 (2.95)
1.6491 (41.89)	50.3	1.096E-07 (2.784E-05)	2.69 (2.96)
1.6518 (41.96)	75.4	1.166E-07 (2.963E-06)	2.70 (2.97)
1.6550 (42.03)	100.6	1.291E-07 (3.278E-06)	2.71 (2.98)
1.6583 (42.12)	125.7	1.291E-07 (3.280E-06)	2.72 (2.99)
1.6614 (42.20)	150.9	1.307E-07 (3.319E-06)	2.73 (3.00)
1.6649 (42.29	176.1	1.478E-07 (3.754E-06)	2.74 (3.01)
1.6689 (42.39)	201.2	1.525E-07 (3.873E-06)	2.75 (3.03)
1.6726 (42.48)	226.4	1.525E-07 (3.874E-06)	2.77 (3.04)
1.6766 (42.58)	251.6	1.613E-07 (4.096E-06)	2.78 (3.05)
1.6807 (42.69)	276.7	1.558E-07 (3.957E-06)	2.79 (3.07)
1.6844 (42.78)	301.9	1.433E-07 (3.639E-06)	2.80 (3.08)
1.6879 (42.87)	327.0	1.393E-07 (3.539E-06)	2.82 (3.09)
1.6914 (42.96)	352.2	1.431E-07 (3.635E-06)	2.83 (3.11)
1.6951 (43.05	377.3	1.556E-07 (3.953E-06)	2.84 (3.12)
1.6992 (43.16)	402.5	1.604E-07 (4.075E-06)	2.85 (3.14)
1.7032 (43.26)	427.6	1.637E-07 (4.158E-06)	2.87 (3.15)
1.7075 (43.37)	452.8	1.801E-07 (4.575E-06)	2.88 (3.17)
1.7122 (43.49)	477.9	1.841E-07 (4.675E-06)	2.90 (3.18)
1.7167 (43.60)	503.0	1.61eE-07 (4.098E-06)	2.91 (3.20)
1.7203 (43.70)	528.2	1.402E-07 (3.561E-06)	2.93 (3.22)
1.7238 (43.78)	553.3	1.417E-07 (3.600E-06)	2.94 (3.23)
1.7275 (43.88)	578.5	1.496E-07 (3.799E-06)	2.95 (3.24)
1.7313 (43.97)	603.6	1.558E-07 (3.959E-06)	2.96 (3.26)
1.7353 (44.08)	628.7	1.637E-07 (4.158E-06)	2.98 (3.27)
1.7395 (44.18)	653.8	1.660E-07 (4.217E-06)	2.99 (3.29)
1.7437 (44.29)	679.0	1.543E-07 (3.918E-06)	3.01 (3.31)
1.7473 (44.38)	704.1	1.543E-07 (3.919E-06)	3.02 (3.32)
1.7514 (44.48)	729.3	1.660E-07 (4.217E-06)	3.04 (3.34)
1.7556 (44.59)	754.4	1.629E-07 (4.138E-06)	3.05 (3.36)
1.7596 (44.69)	779.5	1.582E-07 (4.018E-06)	3.07 (3.37)
1.7636 (44.79)	804.7	1.559E-07 (3.959E-06)	3.09 (3.39)
1.7674 (44.89)	829.8	1.543E-07 (3.919E-06)	3.10 (3.41)
1.7713 (44.99)	854.9	1.566E-07 (3.978E-06)	3.12 (3.42)
1.7753 (45.09)	880.1	1.590E-07 (4.038E-06)	3.13 (3.44)
1.7793 (45.19)	905.2	1.621E-07 (4.118E-06)	3.15 (3.46)
1.7835 (45.29)	930.3	1.692E-07 (4.297E-06)	3.16 (3.48)
1.7878 (45.41)	955.5	1.793E-07 (4.555E-06)	3.18 (3.50)
1.7925 (45.53)	980.6	1.786E-07 (4.536E-06)	3.20 (3.52)

TABLE 19. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		T-97 (Continued)	
1.7968 (45.64)	1005.7	1.762E-07 (4.476E-06)	3.22 (3.54)
1.8013 (45.75)	1030.9	1.833E-07 (4.655E-06)	3.24 (3.56)
1.8060 (4587)	1056.0	1.864E-07 (4.735E-06)	3.26 (3.58)
1.8107 (45.99)	1081.1	1.911E-07 (4.854E-06)	3.28 (3.60)
1.8156 (46.12)	1106.3	1.966E-07 (4.993E-06)	3.30 (3.62)
1.8206 (46.24)	1131.4	2.076E-07 (5.272E-06)	3.32 (3.65)
1.8261 (46.38)	1156.5	2.224E-07 (5.650E-06)	3.34 (3.67)
1.8318 (46.57)	1181.7	2.295E-07 (5.829E-06)	3.37 (3.70)
1.8376 (46.67)	1206.8	2.350E-07 (5.968E-06)	3.40 (3.73)
1.8436 (46.83)	1231.9	2.326E-07 (5.909E-06)	3.42 (3.76)
1.8493 (46.97)	1257.1	2.240E-07 (5.690E-06)	3.45 (3.79)
1.8548 (47.11)	1282.2	2.115E-07 (5.372E-06)	3.48 (3.82)
1.8599 (47.24)	1307.3	2.021E-07 (5.133E-06)	3.50 (3.85)
1.8650 (47.37)	1332.5	2.076E-07 (5.272E-06)	3.52 (3.87)
1.8703 (47.51)	1357.6	2.084E-07 (5.292E-06)	3.55 (3.90)
1.8755 (47.64)	1382.7	2.107E-07 (5.352E-06)	3.57 (3.93)
1.8809 (47.78)	1407.9	2.170E-05 (5.511E-06)	3.60 (3.96)
1.8864 (47.91)	1433.0	2.137E-07 (5.429E-06)	3.63 (3.99)
1.8917 (48.05)	1458.1	2.036E-07 (5.170E-06)	3.66 (4.02)
1.8966 (48.17)	1483.3	1.974E-07 (5.013E-06)	3.68 (4.05)
1.9016 (48.30)	1508.4	1.903E-07 (4.834E-06)	3.71 (4.08)
1.9062 (48.42)	1533.5	1.856E-07 (4.715E-06)	3.73 (4.10)
1.9109 (48.54)	1558.7	1.856E-07 (4.715E-06)	3.76 (4.13)
1.9155 (48.65)	1583.8	2.005E-07 (5.093E-06)	3.78 (4.16)
1.9210 (48.79)	1608.9	2.083E-07 (5.290E-06)	3.81 (4.19)
1.9260 (48.92)	1634.1	2.002E-07 (5.085E-06)	3.84 (4.22)
1.9311 (49.05)	1659.3	2.121E-07 (5.388E-06)	3.87 (4.25)
1.9366 (49.19)	1684.4	2.138E-07 (5.431E-06)	3.90 (4.29)
1.9418 (49.32)	1709.5	2.044E-07 (5.192E-06)	3.93 (4.32)
1.9469 (49.45)	1734.7	2.107E-07 (5.351E-06)	3.96 (4.35)
1.9524 (49.59)	1759.8	2.177E-07 (5.530E-06)	3.99 (4.39)
1.9579 (49.73)	1784.9	2.169E-07 (5.510E-06)	4.03 (4.42)
1.9633 (49.87)	1810.1	2.237E-07 (5.683E-06)	4.06 (4.46)
1.9701 (50.04)	1839.3	2.289E-07 (5.815E-06)	4.10 (4.51)
1.9766 (50.20)	1868.0	2.269E-07 (5.764E-06)	4.14 (4.55)
1.9827 (50.36)	1894.8	2.316E-07 (5.884E-06)	4.18 (4.59)
1.9886 (50.51)	1919.9	2.270E-07 (5.766E-06)	4.22 (4.54)
1.9941 (50.65)	1945.1	2.138E-07 (5.431E-06)	4.26 (4.68)
1.9994 (50.78)	1970.2	2.217E-07 (5.630E-06)	4.29 (4.72)
2.0052 (50.93)	1995.3	2.365E-07 (6.008E-06)	4.33 (4.76)
2.0113 (51.08)	2020.5	2.436E-07 (6.187E-06)	4.37 (4.81)

TABLE 19. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		T-97 (Continued)	
2.0175 (51.24)	2045.6	2.450E-07 (6.222E-06)	4.42 (4.85)
2.0236 (51.40)	2070.8	2.535E-07 (6.438E-06)	4.46 (4.90)
2.0302 (51.57)	2095.9	2.653E-07 (6.739E-06)	4.51 (4.95)
2.0369 (51.74)	2121.1	3.768E-07 (9.571E-06)	4.56 (5.01)
2.0492 (52.05)	2146.2	5.351E-07 (1.359E-05)	4.65 (5.11)
2.0638 (52.42)	2171.3	5.607E-07 (1.424E-05)	4.77 (5.24)
2.0774 (52.76)	2196.5	5.333E-07 (1.355E-05)	4.88 (5.36)
2.0906 (53.10)	2221.6	5.316E-07 (1.350E-05)	4.99 (5.48)
2.1041 (53.44)	2246.8	5.519E-07 (1.402E-05)	5.11 (5.61)
2.1184 (53.81)	2271.9	5.865E-07 (1.490E-05)	5.24 (5.76)
2.1336 (54.19)	2297.0	6.171E-07 (1.567E-05)	5.38 (5.92)
2.1494 (54.59)	2322.2	6.468E-07 (1.643E-05)	5.54 (6.09)
2.1661 (55.02)	2347.3	6.812E-07 (1.730E-05)	5.72 (6.28)
2.1837 (55.46)	2372.5	7.156E-07 (1.818E-05)	5.91 (6.50)
2.2021 (55.93)	2397.6	7.672E-07 (1.949E-05)	6.13 (6.74)
2.2222 (56.44)	2422.7	8.423E-07 (2.139E-05)	6.38 (7.01)
2.2421 (56.95)	2445.4	9.651E-07 (2.451E-05)	6.65 (7.31)
2.2659 (57.55)	2468.0		6.99 (7.68)
		T-98	
1.5610 (39.65)	0.0		2.84 (3.12)
1.5690 (39.85)	170.0	1.114E-07 (2.829E-06)	2.87 (3.15)
1.6080 (40.84)	376.0	1.976E-07 (5.020E-06)	2.99 (3.29)
1.6500 (41.91)	580.0	2.411E-07 (6.124E-06)	3.13 (3.44)
1.7070 (43.36)	786.0	2.264E-07 (5.750E-06)	3.35 (3.68)
1.7540 (44.55)	1100.0	2.409E-07 (6.120E-06)	3.54 (3.89)
1.7810 (45.24)	1200.0	2.850E-07 (7.239E-06)	3.67 (4.03)
1.8440 (46.84)	1400.0	3.650E-07 (9.271E-06)	3.98 (4.37)
1.9270 (48.94)	1600.0	5.125E-07 (1.302E-05)	4.47 (4.91)
2.0490 (52.04)	1800.0	8.375E-07 (2.127E-05)	5.40 (5.94)
2.2620 (57.45)	2000.0		8.05 (8.85)
		T-99	
1.6598 (42.16)	0.0		3.71 (4.07)
1.6618 (42.21)	32.2	7.698E-08 (1.930E-06)	3.71 (4.08)
1.6647 (42.28)	64.3	9.250E-08 (2.349E-06)	3.73 (4.10)
1.6678 (42.36)	96.4	8.330E-08 (2.116E-06)	3.74 (4.11)
1.6701 (42.42)	128.5	6.554E-08 (1.665E-06)	3.75 (4.12)
1.6720 (42.47)	160.7	6.492E-08 (1.649E-06)	3.76 (4.13)

TABLE 19. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		T-99 (Continued)	
1.6742 (42.42)	192.8	7.784E-08 (1.977E-06)	3.77 (4.14)
1.6770 (42.60)	224.9	7.106E-08 (1.805E-06)	3.78 (4.15)
1.6788 (42.64)	257.1	7.168E-08 (1.821E-06)	3.79 (4.16)
1.6816 (42.71)	289.2	1.016E-07 (2.582E-06)	3.80 (4.18)
1.6853 (42.81)	321.4	8.384E-08 (2.130E-06)	3.82 (4.19)
1.6870 (42.85)	353.5	6.919E-08 (1.758E-06)	3.82 (4.20)
1.6898 (42.92)	385.7	1.078E-07 (2.739E-06)	3.84 (4.22)
1.6939 (43.02)	417.8	1.164E-07 (2.956E-06)	3.86 (4.24)
1.6973 (43.11)	450.0	1.121E-07 (2.847E-06)	3.87 (4.25)
1.7011 (43.21)	482.1	1.318E-07 (3.347E-06)	3.89 (4.27)
1.7057 (43.32)	514.2	1.146E-07 (2.910E-06)	3.91 (4.30)
1.7085 (43.40)	546.4	1.287E-07 (3.269E-06)	3.92 (4.31)
1.7140 (43.54)	578.5	1.427E-07 (3.626E-06)	3.95 (4.34)
1.7177 (43.63)	610.7	1.397E-07 (3.548E-06)	3.97 (4.36)
1.7230 (43.76)	642.8	1.372E-07 (3.486E-06)	3.99 (4.39)
1.7265 (43.85)	674.9	1.434E-07 (3.642E-06)	4.01 (4.40)
1.7322 (44.00)	707.1	1.568E-07 (3.983E-06)	4.04 (4.43)
1.7366 (44.11)	739.2	1.764E-07 (4.481E-06)	4.06 (4.46)
1.7435 (44.28)	771.4	1.698E-07 (4.312E-06)	4.09 (4.50)
1.7475 (44.38)	803.5	1.428E-07 (3.627E-06)	4.11 (4.52)
1.7527 (44.52)	835.6	1.788E-07 (4.541E-06)	4.14 (4.55)
1.7590 (44.68)	867.8	2.027E-07 (5.149E-06)	4.17 (4.58)
1.7657 (44.85)	899.9	1.826E-07 (4.638E-06)	4.21 (4.62)
1.7707 (44.98)	932.0	1.538E-07 (3.906E-06)	4.23 (4.65)
1.7756 (45.10)	964.1	1.833E-07 (4.655E-06)	4.26 (4.68)
1.7825 (45.27)	996.3	2.021E-07 (5.133E-06)	4.30 (4.72)
1.7886 (45.43)	1028.4	2.432E-07 (6.178E-06)	4.33 (4.76)
1.7981 (45.67)	1060.5	1.962E-07 (4.982E-06)	4.38 (4.81)
1.8012 (45.75)	1092.7	2.189E-07 (5.559E-06)	4.40 (4.83)
1.8122 (46.03)	1124.8	2.728E-07 (6.928E-06)	4.46 (4.90)
1.8187 (46.20)	1156.9	2.241E-07 (5.692E-06)	4.50 (4.95)
1.8266 (46.39)	1189.1	2.736E-07 (6.949E-06)	4.55 (5.00)
1.8363 (46.64)	1221.3	3.038E-07 (7.717E-06)	4.61 (5.06)
1.8461 (46.89)	1253.4	2.918E-07 (7.411E-06)	4.67 (5.13)
1.8551 (47.12)	1285.5	2.872E-07 (7.295E-06)	4.72 (5.19)
1.8646 (47.36)	1317.7	3.375E-07 (8.573E-06)	4.79 (5.26)
1.7868 (47.67)	1349.8	2.849E-07 (7.238E-06)	4.87 (5.35)
1.8829 (47.82)	1382.0	1.205E-07 (3.061E-06)	4.91 (5.39)
1.8845 (47.87)	1414.1	4.720E-07 (1.199E-05)	4.92 (5.41)
1.9132 (48.59)	1446.2	5.998E-07 (1.523E-05)	5.12 (5.63)
1.9229 (48.84)	1475.1	3.374E-07 (8.570E-06)	5.19 (5.71)
1.9525 (49.59)	1561.9	3.598E-07 (9.139E-06)	5.42 (6.96)

TABLE 19. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, in/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		T-99 (Continued)	
1.9620 (49.83)	1588.0	3.634E-07 (9.230E-06)	5.50 (6.05)
1.9714 (50.07)	1614.0	3.241E-07 (8.232E-06)	5.58 (6.13)
1.9789 (50.26)	1640.1	3.498E-07 (8.885E-06)	5.65 (6.20)
1.9896 (50.54)	1666.1	3.928E-07 (9.978E-06)	5.74 (6.31)
1.9994 (50.78)	1692.2	3.755E-07 (9.537E-06)	5.83 (6.40)
2.0092 (51.03)	1718.3	3.173E-07 (8.060E-06)	5.92 (6.50)
2.0159 (51.20)	1744.3	3.476E-07 (8.828E-06)	5.98 (6.57)
2.0273 (51.49)	1770.4	4.314E-07 (1.096E-06)	6.09 (6.69)
2.0384 (51.77)	1796.4	4.761E-07 (1.209E-05)	6.20 (6.81)
2.0521 (52.12)	1822.5	5.609E-07 (1.425E-05)	6.34 (6.97)
2.0676 (52.52)	1848.5	5.661E-07 (1.438E-05)	6.51 (7.15)
2.0816 (52.87)	1874.6	6.104E-07 (1.550E-05)	6.67 (7.32)
2.0994 (53.32)	1900.6	6.429E-07 (1.633E-05)	6.87 (7.55)
2.1151 (53.72)	1926.7	6.889E-07 (1.750E-05)	7.07 (7.76)
2.1353 (54.24)	1952.7	7.320E-07 (8.859E-05)	7.33 (8.05)
2.1516 (54.65)	1976.2	7.259E-07 (1.844E-05)	7.55 (8.29)
2.1694 (55.10)	1999.7	8.645E-07 (2.196E-05)	7.80 (8.57)
2.1921 (55.68)	2023.1	9.030E-07 (2.294E-05)	8.15 (8.96)
2.2099 (56.13)	2044.2	8.403E-07 (2.134E-05)	8.44 (9.27)
2.2276 (56.58)	2065.4	9.212E007 (2.340E-05)	8.75 (9.61)
2.2489 (57.12)	2086.5	1.135E-06 (2.882E-05)	9.14(10.04)
2.2727 (57.73)	2105.5	1.262E-06 (3.205E-05)	9.61(10.56)
2.2945 (58.28)	2122.7	1.497E-06 (3.803E-05)	10.08(11.07)
2.3208 (58.95)	2138.1		10.69(11.75)

Specimen Identification	Thickness, B, inch (mm)	Width, W, inch (mm)
T-97	1.491 (37.87)	3.013 (76.53)
T-98	1.491 (37.87)	3.014 (76.63)
T-99	1.491 (37.87)	3.017 (76.53)

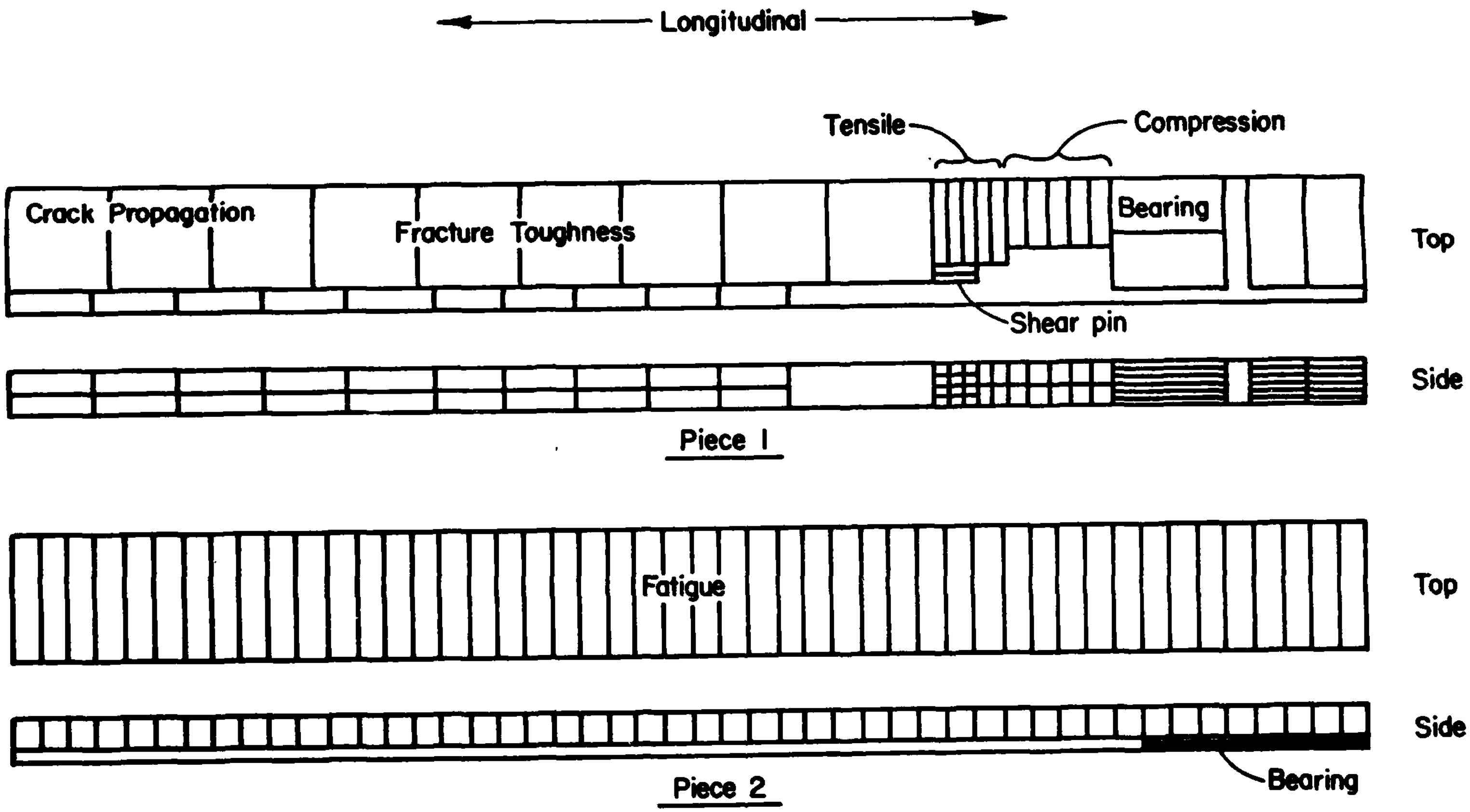


Figure 14. Location of specimens for CT-91-T7E69.

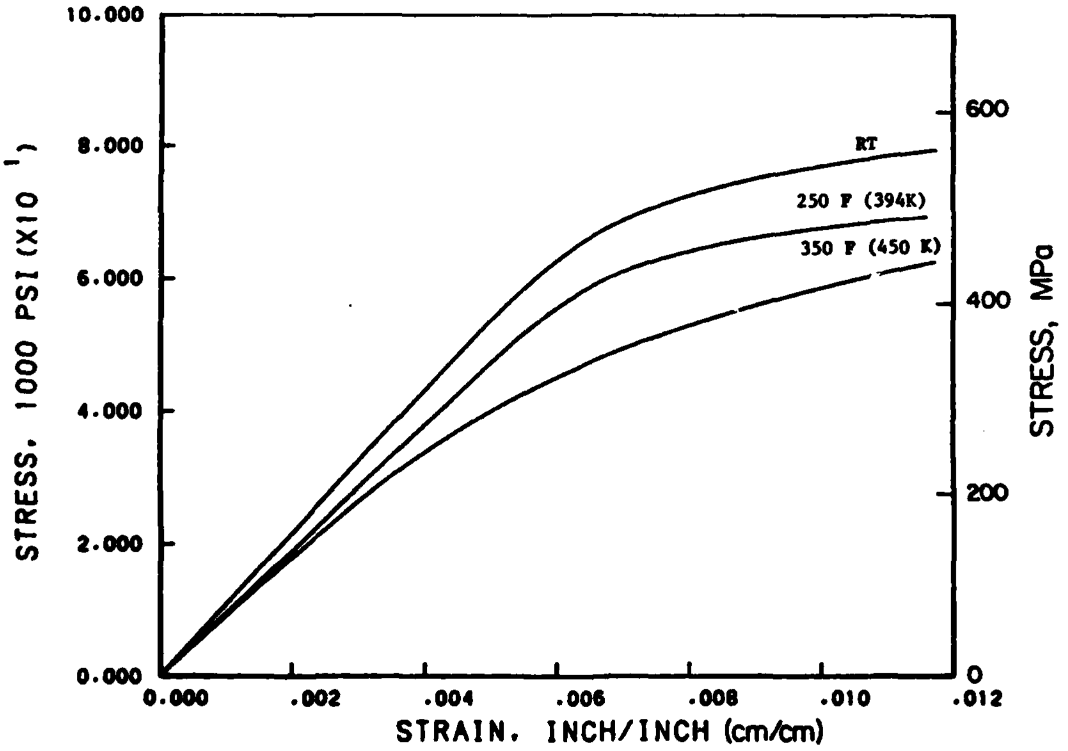


Figure 15. Typical tensile stress-strain curves for longitudinal CT-91-T7E69 aluminum extrusion.

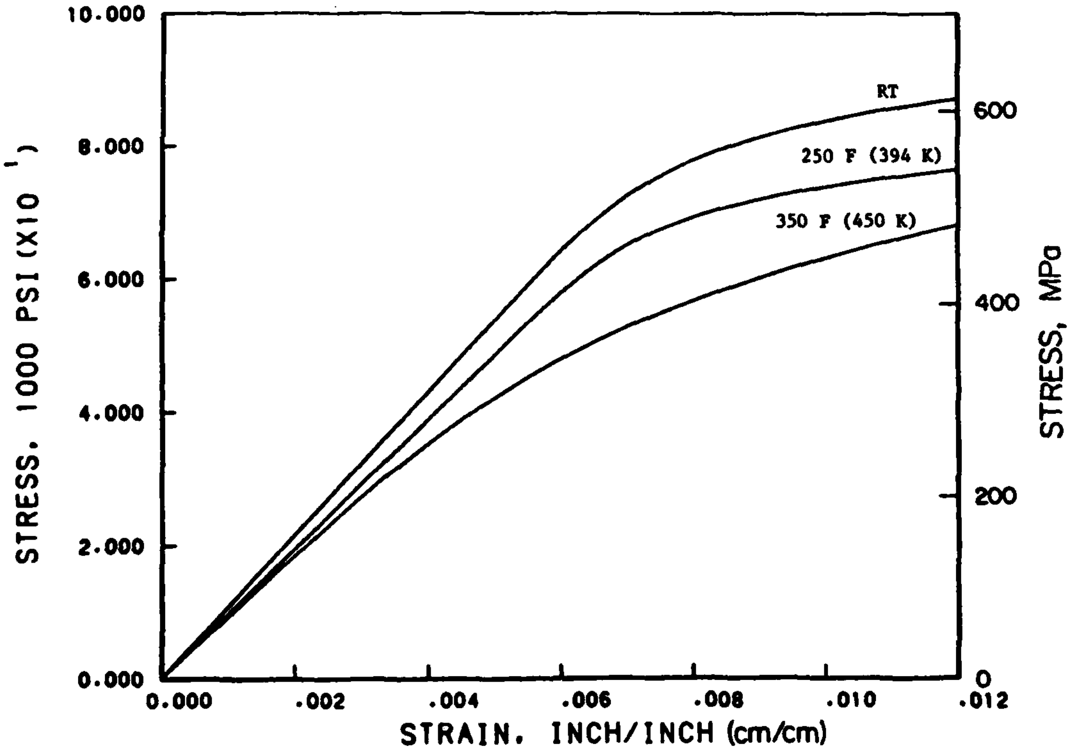
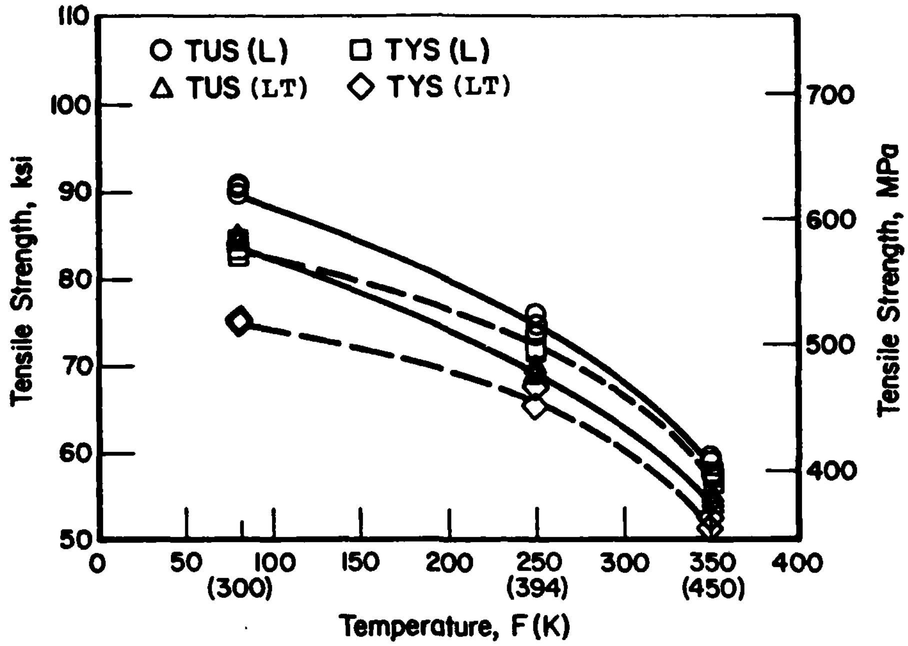


Figure 16. Typical tensile stress-strain curves for long transverse CT-91-T7E69 aluminum extrusion.



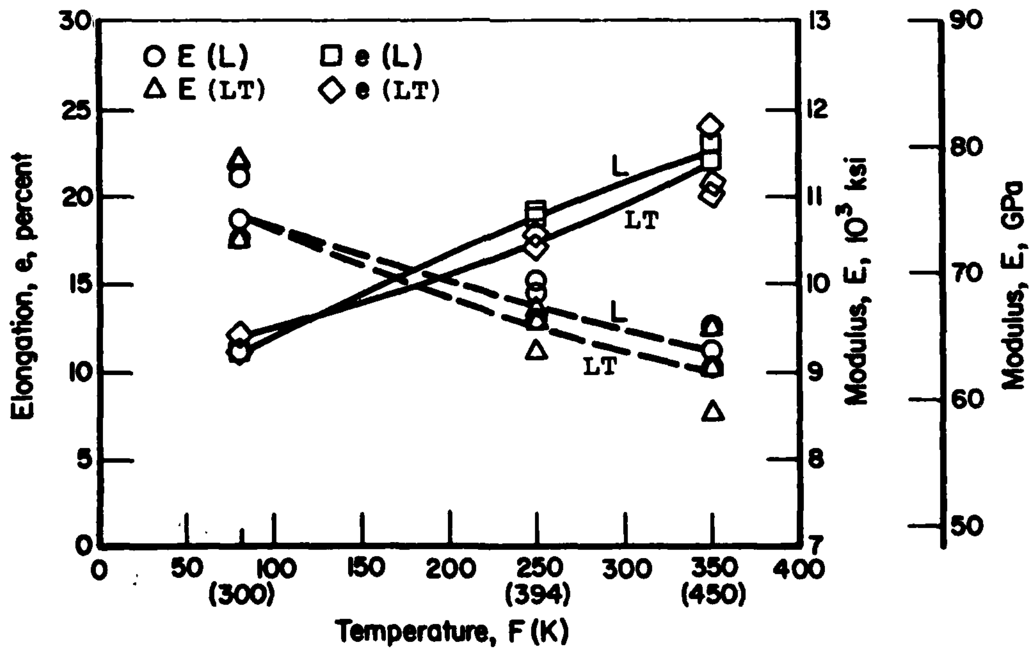


Figure 17. Effect of temperature on tensile properties of CT-91-T7E69 aluminum extrusions.

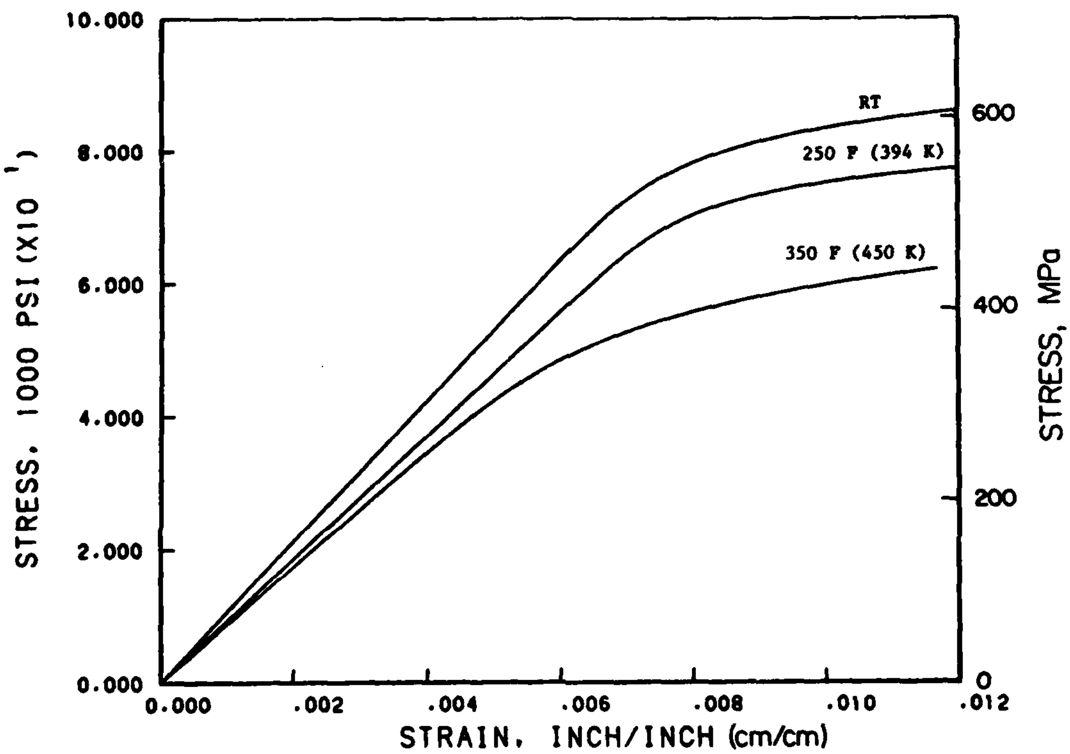


Figure 18. Typical compressive stress-strain curves for longitudinal CT-91-T7E69 aluminum extrusion.

THIS

PAGE

IS

MISSING

IN

ORIGINAL

DOCUMENT

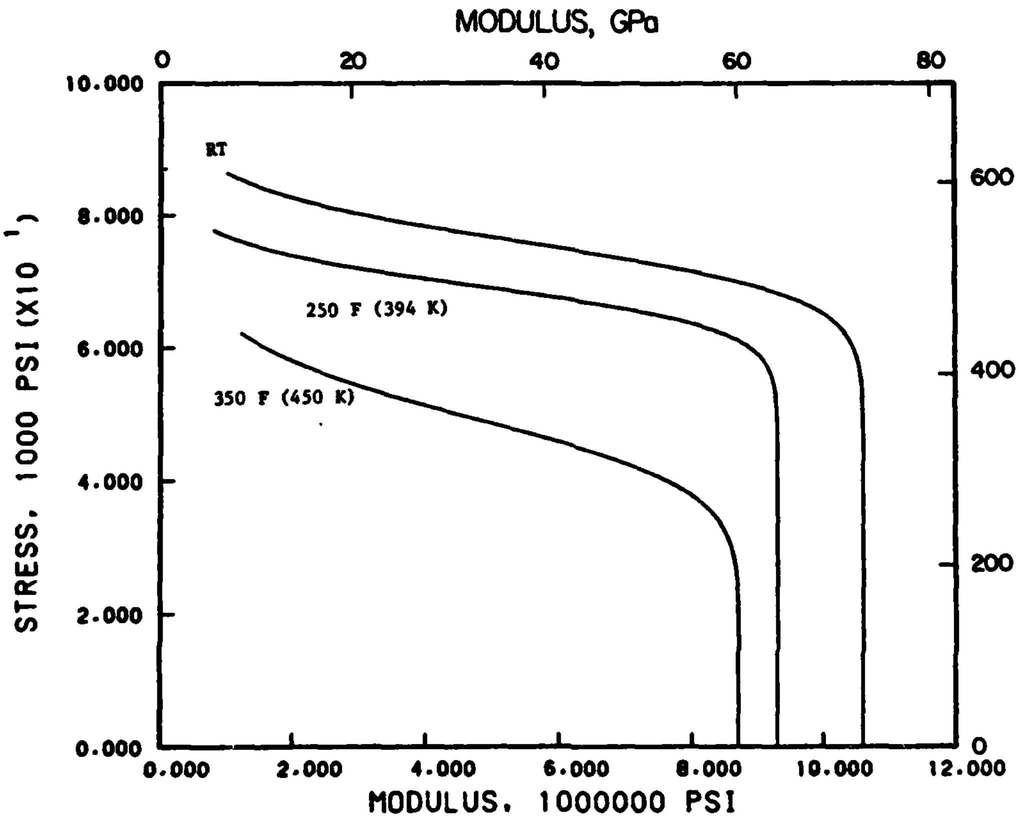


Figure 20. **Typical compressive tangent-modulus curves for longitudinal CT-91-T7E69 aluminum extrusion.**

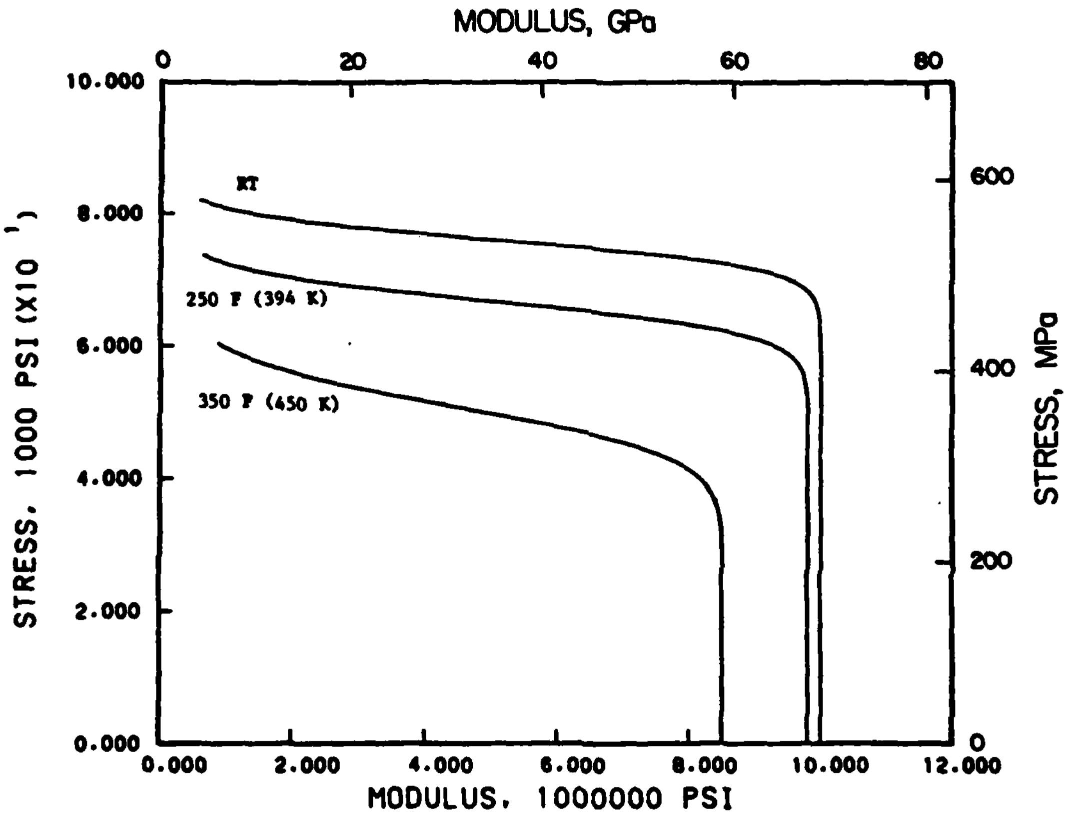


Figure 21. Typical compressive tangent-modulus curves for long transverse CT-91-T7E69 aluminum extrusion.

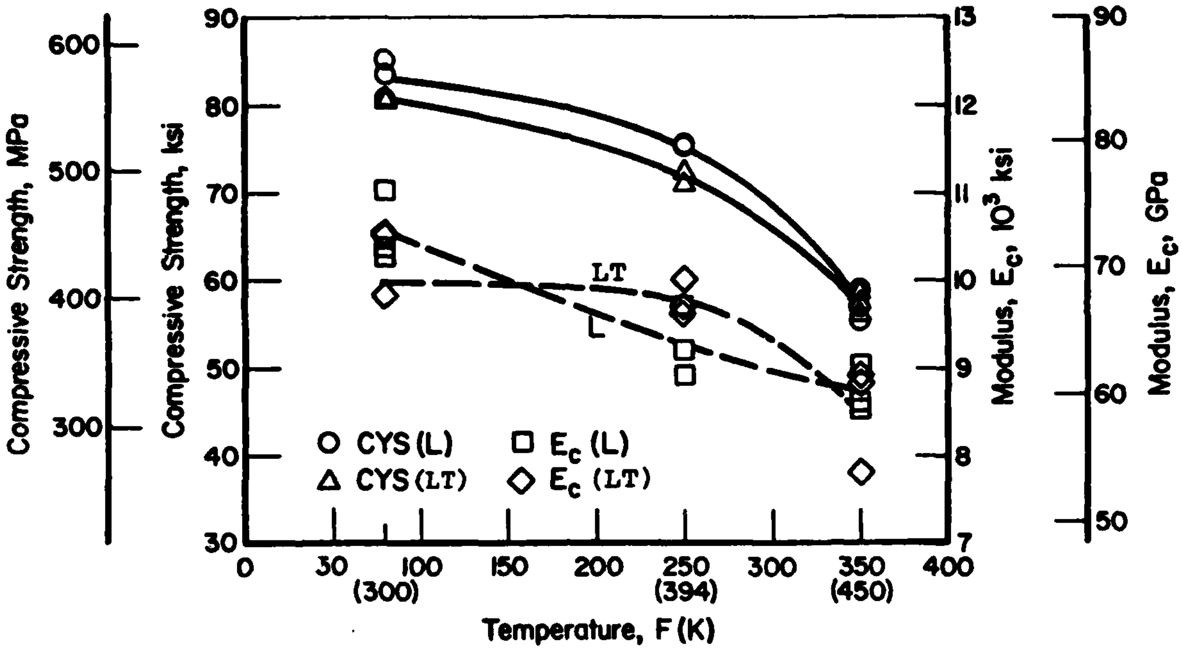


Figure 22. Effect of temperature on the compressive properties of CT-91-T7E69 aluminum extrusion.

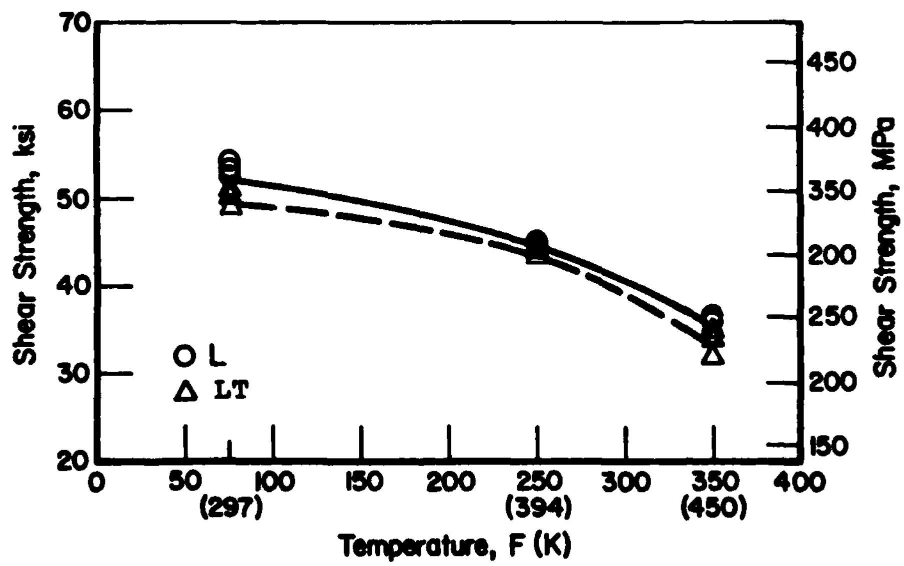


Figure 23. Effect of temperature on pin shear properties of CT-91-T7E69 aluminum extrusion.

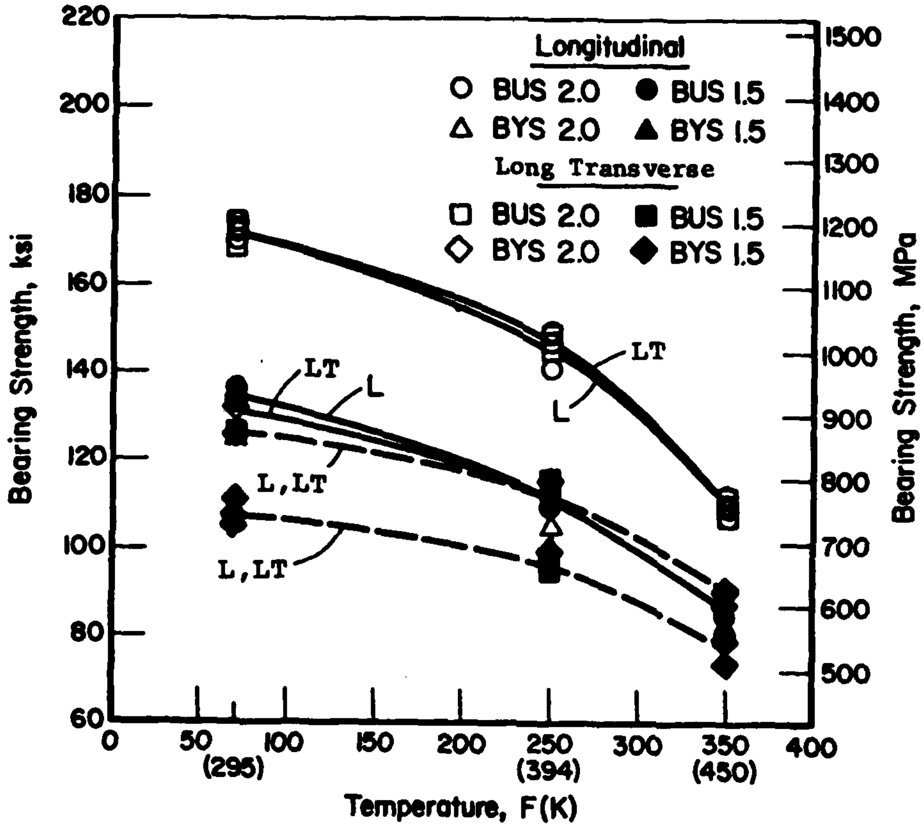


Figure 24. Effect of temperature on the bearing properties of CT-91-T7E69 aluminum extrusion.

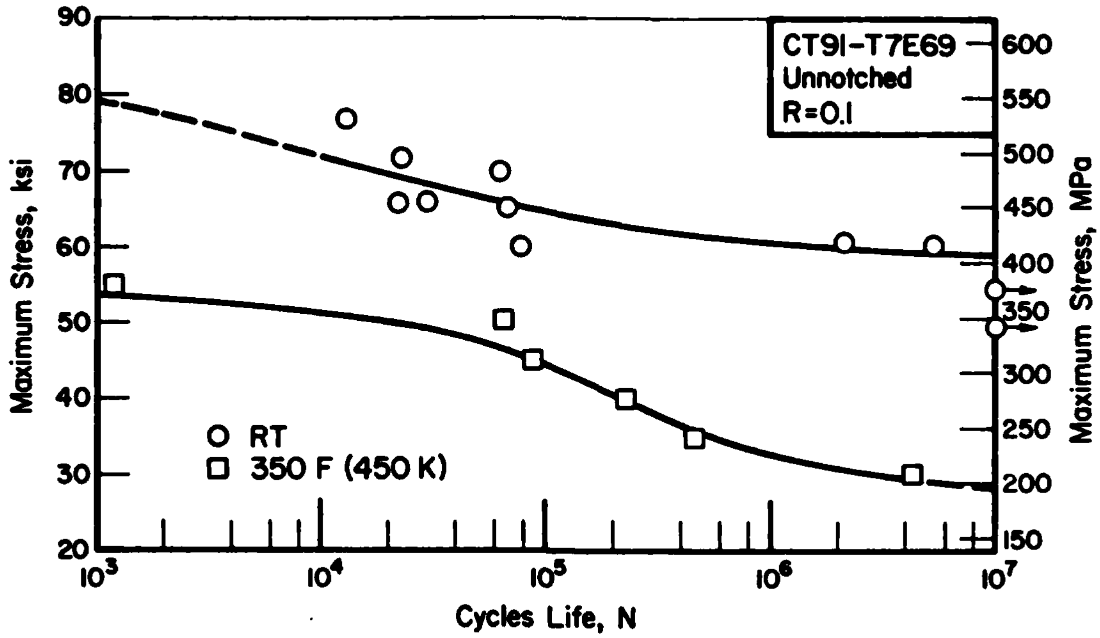


Figure 25. Axial load fatigue behavior of unnotched long transverse CT-91-T7E69 aluminum extrusion.

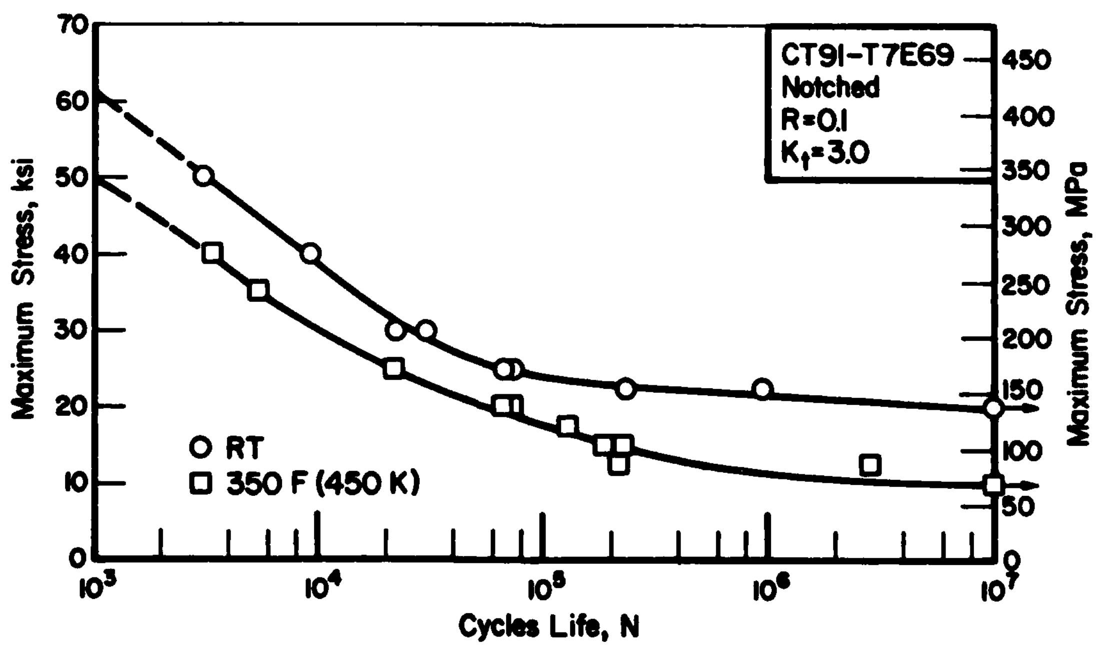


Figure 26. Axial load fatigue behavior of notched (K_t = 3.0) long transverse CT-91-E7E69 aluminum extrusion.

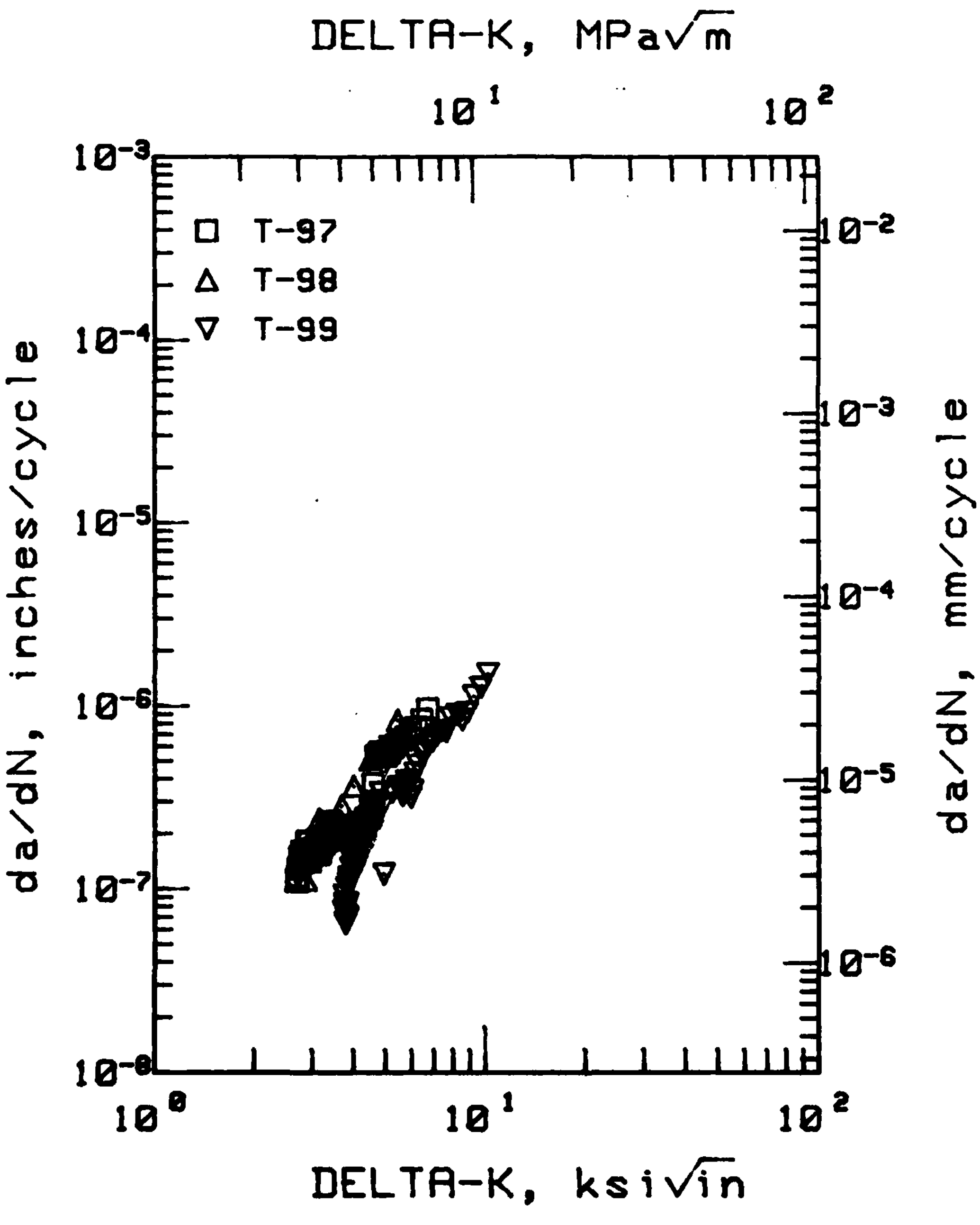


Figure 27. Plot of da/dN versus delta K for CT-91-T7E69 aluminum extrusion.

Lab Air
R = 0.1
Frequency = 20Hz
Grain Orientation = LT

Ti-10V-2Fe-3Al Isothermally Forged Pancake

Material Description

Ti-10V-2Fe-3Al is a recently developed, metallurgically near-beta alloy. The alloy is capable of attaining a variety of strength levels, depending on the selection of heat treatment. A major advantage over other alloys is the excellent forgeability. It forms readily at temperatures below those required for Ti-6Al-4V.

The Ti-10V-2Fe-3Al material used in this evaluation was received as six pancakes, 7 inches (178 mm) in diameter x 1/2-inch (12.7 mm) thick, The material was produced by RMI and isothermally forged by TRW.

The chemical composition of this lot is as follows:

Chemical Composition	Percent Weight
Vanadium	9.5
Aluminum	3.2
Iron	1.9
Titanium	Balance

Processing and Heat Treating

A 30-inch (762 mm) diameter cast ingot was first heated to 2200 F (1478 K) and forged to a 24-inch (610 mm) round cornered square (RCS). The billet was then heated to 1400 F (1033 K) and forged to a 20-inch (508 mm) RCS, reheated to 1700 F (1200 K) and forged to a 15-inch (381 mm) RCS, reheated to 1700 F (1200 K) and once more forged to an 11-inch (279 mm) RCS bar. Conditioning of the piece was conducted as needed during the processing. A section of the material was cut, heated to 1375 F (1019 K) and forged into an 8-inch (203 mm) RCS, reheated to 1700 F (1200 K) and forged to a 5-inch (127 mm) RCS, reheated to 1500 F (1089 K) and forged to a 4-inch (102 mm) octagon. A final pass at RMI was performed in a rotary forging machine at 1500 F (1089 K) transforming the octagon into a 3-1/4-inch (82.6 mm) diameter round bar.

At TRW the round bar was conventionally upset 25% at 1525 F (1103 K), conventionally drawn 40% at 1525 F (1103 K), isothermally drawn 50% at 1525 F (1103 K), and isothermally forged 50% to the final shape. The material was subsequently heat treated as follows: 1435 F (1052 K)/ 2 hours/air cool, 1425 F (1047 K)/2 hours/water quench, and 945 F (780 K)/ 8 hours/air cool (STA).

Test Results

Location of test specimens is shown in Figures 28 a, b, and c.

Tests were conducted at the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base. No stress-strain or tangent-modulus curves were available.

Tension. Tests were conducted using longitudinal and long transverse specimens at room temperature and 600 F (589 K) with the results shown in Table 20.

Compression. Tests were conducted using longitudinal and long transverse specimens at room temperature with the results presented in Table 21.

Shear. Room temperature test results for longitudinal and long transverse specimens are shown in Table 22.

Bearing. Results of room temperature tests are shown in Table 23 for longitudinal and transverse specimens at e/D of 1.5 and 2.0.

Fatigue. Axial load, long transverse fatigue test results at room temperature are shown in Table 24 for unnotched and, in Table 25, for notched (K_t = 3.0) specimens. The S-N curves are presented in Figure 29.

Crack-Growth. Test results for compact tension, fatigue-crack-propagation L-T orientation specimens at room temperature are given in Table 26, and the 600 K (589 K) test results are presented in Table 27. Figure 30 shows da/dN versus ΔK at room temperature, while Figure 31 shows the 600 F (589 K) data.

TABLE 20. TENSILE TEST RESULTS FOR STA Ti-10V-2Fe-3Al PANCAKE

Specimen Identi- fication	Ultimate Tensile Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 1 Inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus[a], 10^3 ksi (GPa)
		Room Temperature, Longitudinal			
L-1	175.7 (1211.2)	169.0 (1164.9)	3.0	2.5	15.1 (103.9)
L-2	173.9 (1199.1)	167.6 (1155.6)	2.0	4.0	15.3 (105.5)
L-3	188.0 (1296.1)	185.3 (1277.8)	2.0	4.0	16.0 (110.4)
Average	179.2 (1235.5	174.0 (1199.4)	2.3	3.5	15.5 (106.6)
		Room Temperature, Long Transverse			
T-1	180.7 (1246.1)	175.3 (1208.3)	2.0	3.5	15.2 (105.0)
T-5	177.1 (1221.1)	170.6 (1176.1)	2.0	3.3	14.9 (102.5)
T-6	178.6 (1231.6)	175.3 (1208.4)	2.0	3.3	15.3 (105.3)
Average	178.8 (1232.9	173.7 (1197.6)	2.0	3.3	15.1 (104.2)
		600 F (589 K), Longitudinal			
L-4	161.7 (1115.1)	146.5 (1010,3)	2.8	7.0	14.8 (102.0)
L-5	148.9 (1026.4)	132.3 (912.4)	11.5	53.8	13.0 (89.9)
L-6	149.1 (1027.9)	131.0 (903.3)	10.7	48.9	14.1 (97.4)
Average	153.2 (1056.5)	136.6 (942.0)	8.33	36.6	14.0 (96.4)
		600 F (589 K), Long Transverse			
T-4	152.2 (1049.1)	142.9 (985.4)	3.2	9.5	15.4 (106.2)
T-2	154.6 (1065.6)	137.0 (944.5)	9.8	43.2	14.0 (96.2)
T-3	157.9 (1088.8)	143.7 (991.1)	6.5	32.9	12.6 (86.7)
Average	154.9 (1067.8)	141.2 (973.7)	6.5	28.5	14.0 (96.4)

[a]The values presented are indicative of modulus values typical for titanium alloy materials; however, the instrumentation did not meet ASTM E83 Class A extensometer requirements.

TABLE 21. ROOM TEMPERATURE COMPRESSION TEST RESULTS FOR STA Ti-10V-2Fe-3Al PANCAKE

Specimen Identification	Ultimate[a] Strength, ksi (MPa)	Compressive[b] Modulus, 10^3 ksi (GPa)
	Longitudinal	
L-8	216.0 (1489.0)	16.9 (116.6)
L-9	211.5 (1458.4)	16.3 (112.3)
Average	213.7 (1473.7)	16.6 (114.5)

Specimen Identification	0.2 Percent Offset Yield Strength, ksi (MPa)	Compressive[b] Modulus, 10^3 ksi (GPa)
	Long Transverse	
T-10	193.7 (1335.2)	16.1 (111.6)
T-11	192.4 (1326.7)	16.1 (111.3)
T-12	189.4 (1305.6)	15.9 (109.8)
Average	191.8 (1322.5)	16.1 (110.9)

[a]Due to testing problems, the data for longitudinal specimens are ultimate strength values.

[b]The values presented are indicative of modulus values typical for titanium alloy materials; however, the instrumentation did not meet ASTM E-83 Class A extensometer requirements.

TABLE 22. PIN SHEAR TEST RESULTS FOR STA Ti-10V-2Fe-3Al PANCAKE

Specimen Identification	Longitudinal Ultimate Shear Strength, ksi (MPa)	Specimen Identification	Long Transverse Ultimate Shear Strength, ksi (MPa)
L-13	97.4 (671.4)	T-16	103.7 (715.0)
L-14	101.4 (698.8)	T-17	102.3 (705.1)
L-15	97.2 (670.0)	T-18	98.7 (700.2)
Average	98.6 (680.1)	Average	101.6 (700.2)

TABLE 23. BEARING TEST RESULTS AT e/D = 1.5 AND e/D = 2.0 FOR STA Ti-10V-2Fe-3Al PANCAKE

Specimen Identification	Bearing Yield Strength, ksi (MPa)	Bearing Ultimate Strength, ksi (MPa)
	e/D = 1.5, Longitudinal	
L-19	248.8 (1715.1)	255.3 (1760.3)
L-20	237.7 (1638.8)	243.4 (1678.4)
L-21	242.6 (1672.5)	242.6 (1672.5)
Average	243.0 (1675.5)	247.1 (1703.8
	e/D = 1.5, Long Transverse	
T-22	254.1 (1751.9)	265.6 (1831.0)
T-23	262.7 (1811.2)	263.9 (1819.7)
T-24	260.0 (1792.8)	265.0 (1827.0)
Average	258.9 (1785.3)	264.8 (1825.9)
	e/D = 2.0, Longitudinal	
L-25	291.4 (2009.0)	329.5 (2271.8)
L-26	297.8 (2053.0)	315.2 (2173.3)
L-27	280.7 (1935.5)	318.8 (2198.3)
Average	290.0 (1999.2)	321.2 (2214.5)
	e/D = 2.0, Long Transverse	
T-28	271.7 (1873.3)	329.3 (2270.6)
T-29	288.0 (1985.9)	312.4 (2153.7)
T-30	282.8 (1949.7)	286.9 (1977.9)
Average	280.8 (1936.3)	309.5 (2134.1)

TABLE 24. AXIAL LOAD UNNOTCHED FATIGUE TEST RESULTS AT ROOM TEMPERATURE FOR STA Ti-10V-2Fe-3Al PANCAKE - LONG TRANSVERSE

Specimen Identification	Maximum Stress, ksi (MPa)	Cycles to Failure
T-38	150 (1034.2)	3,700
T-34	135 (930.8)	9,700[a]
T-37	130 (896.4)	44,400
T-33	125 (861.9)	55,500[b]
T-32	120 (827.4)	101,600
T-40	117.5 (810.2)	47,200
T-39	115 (792.9)	5,227,300
T-35	112.5 (775.7)	450,500
T-36	110 (758.4)	5,393,300
T-34	107.5 (741.2)	10^7[c]
T-33	105 (724.0)	10^7[c]

[a]Rerun of 107.5 ksi (741.2 MPa).

[b]Rerun of 105 ksi (724 MPa).

[c]Did not fail.

TABLE 25. AXIAL LOAD NOTCHED (K_t = 3.0) FATIGUE TEST RESULTS AT ROOM TEMPERATURE FOR STA Ti-10V-2Fe-3Al PANCAKE - LONG TRANSVERSE

Specimen Identification	Maximum Stress, ksi (MPa)	Cycles to Failure
T-48	85 (586.0)	4,350[a]
T-50	75 (517.1)	7,010
T-44	70 (482.6)	11,200[b]
T-41	60 (413.7)	18,100
T-43	55 (379.2)	28.900[c]
T-47	50 (344.8)	51,600[d]
T-42	45 (310.3)	64,000
T-49	42.5 (293.0)	48,100
T-45	40 (275.8)	54,200
T-48	38.5 (265.4)	11,551,300[e]
T-46	37.5 (258.6)	89,600
T-47	37.5 (258.6)	10^7[e]
T-43	35 (241.3)	10^7[e]
T-44	35 (241.3)	17,385,000[e]

[a]Rerun of 38.5 ksi (265.4 MPa).

[b]Rerun of 35 ksi (241.3 MPa).

[c]Rerun of 35 ksi (241.3 MPa).

[d]Rerun of 37.5 ksi (258.6 MPa).

[e]Test discontinued; did not fail.

TABLE 26. FATIGUE-CRACK-PROPAGATION DATA FOR STA Ti-10V-2Fe-3Al PANCAKE AT ROOM TEMPERATURE - L-T SPECIMEN

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		Ti-10-3	
.0920 (2.34)	10.0		3.59 (3.95)
.1120 (2.84)	50.0	5.000E-07 (1.270E-05)	3.78 (4.16)
.1320 (3.35)	90.0	5.000E-07 (1.270E-05)	3.97 (4.37)
.1520 (3.86)	130.0	5.952E-07 (1.512E-05)	4.16 (4.57)
.1720 (4.37)	160.0	6.500E-07 (1.651E-05)	4.35 (4.78)
.1910 (4.85)	190.0	6.500E-07 (1.651E-05)	4.53 (4.98)
.2110 (5.36)	220.0	7.500E-07 (1.905E-05)	4.72 (5.10)
.2360 (5.99)	250.0	9.333E-07 (2.371E-05)	4.96 (5.45)
.2560 (6.50)	270.0	1.038E-06 (2.636E-05)	5.15 (5.65)
.2820 (7.16)	294.0	1.083E-06 (2.752E-05)	5.39 (5.92)
.3080 (7.82)	318.0	1.166E-06 (2.962E-05)	5.64 (6.19)
.3250 (8.25)	332.0	1.243E-06 (3.157E-05)	5.80 (6.37)
.3520 (8.94)	353.0	1.420E-06 (3.608E-05)	6.06 (6.65)
.3780 (9.60)	370.0	1.638E-06 (4.160E-05)	6.31 (6.93)
.4040 (10.26)	385.0	1.867E-06 (4.741E-05)	6.56 (7.20)
.4340 (11.02)	400.0	2.185E-06 (5.550E-05)	6.85 (7.53)
.4620 (11.73)	412.0	2.375E-06 (6.033E-05)	7.13 (7.83)
.4910 (12.47)	424.0	2.734E-06 (6.943E-05)	7.42 (8.15)
.5310 (13.49)	437.0	3.726E-06 (9.463E-05)	7.83 (8.61)
.5640 (14.32)	445.0	3.981E-06 (1.011E-04)	8.18 (8.99)
.6020 (15.29)	455.0	3.911E-06 (9.934E-05)	8.60 (9.45)
.6340 (16.10)	463.0	4.381E-06 (1.113E-04)	8.96 (9.84)
.6620 (16.81)	469.0	4.790E-06 (1.217E-04)	9.29 (10.20)
.6940 (17.63)	475.5	5.223E-06 (1.327E-04)	9.68 (10.63)
.7270 (18.46)	481.5	5.913E-06 (1.502E-04)	10.09 (11.09)
.7550 (19.15)	486.0	6.237E-06 (1.584E-04)	10.47 (11.50)
.7800 (19.81)	490.0	6.750E-06 (1.715E-04)	10.81 (11.88)
.8090 (20.57)	494.0	7.869E-06 (1.999E-04)	11.24 (12.35)
.8340 (21.18)	497.0	8.667E-06 (2.201E-04)	11.62 (12.77)
.8610 (21.87)	500.0	9.667E-06 (2.455E-04)	12.05 (13.24)
.8920 (22.66)	503.0	1.050E-05 (2.667E-04)	12.58 (13.82)
.9240 (23.47)	506.0	1.205E-05 (3.060E-04)	13.16 (14.47)
.9570 (24.31)	508.5	1.309E-05 (3.325E-04)	13.81 (15.18)
.9830 (24.97)	510.5	1.425E-05 (3.620E-04)	14.36 (15.78)
1.0140 (25.76)	512.5	1.960E-05 (4.977E-04)	15.06 (16.55)
1.0480 (26.62)	514.0	2.517E-05 (6.392E-04)	15.90 (17.47)
1.0720 (27.23)	514.9	3.000E-05 (7.620E-04)	16.54 (18.17)
1.1020 (27.99)	515.8	3.554E-05 (9.027E-04)	17.40 (19.12)
1.1320 (28.75)	516.6	6.583E-05 (1.672E-03)	18.35 (20.16)
1.1640 (29.56)	517.0	8.667E-05 (2.201E-03)	19.45 (21.38)

TABLE 26. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		Ti-10-3 (Continued)	
1.1820 (30.02)	517.2)	9.667E-05 (2.455E-03)	20.13 (22.12)
1.1920 (30.28)	517.3	1.450E-04 (3.683E-03)	20.52 (22.55)
1.2110 (30.76)	517.4	2.250E-04 (5.715E-03)	21.30 (23.41)
1.2370 (31.42)	517.5		22.46 (24.68)
		Ti-10-4	
.1601 (4.07)	15.0		4.24 (4.66)
.1003 (4.58)	60.0	4.932E-07 (1.253E-05)	4.43 (4.87)
.2016 (5.12)	100.0	7.675E-07 (1.949E-05)	4.63 (5.89)
.2417 (6.14)	140.0	8.272E-07 (2.101E-05)	5.01 (5.51)
.2721 (6.91)	190.0	7.068E-07 (1.795E-05)	5.38 (5.82)
.2902 (7.37)	214.0	7.995E-07 (2.831E-05)	5.47 (6.01)
.3168 (8.05)	245.0	1.050E-06 (2.666E-05)	5.72 (6.29)
.3377 (8.58)	263.0	1.448E-06 (3.677E-05)	5.92 (6.51)
.3503 (8.90)	271.0	1.474E-06 (3.744E-05)	6.04 (6.64)
.3757 (9.54)	292.0	1.442E-06 (3.663E-05)	6.29 (6.91)
.4071 (10.34)	311.0	1.493E-06 (3.791E-05)	6.59 (7.24)
.4238 (10.76)	323.0	1.649E-06 (4.189E-05)	6.75 (7.42)
.4578 (11.63)	339.9	2.128E-06 (5.406E-05)	7.09 (7.79)
.4800 (12.19)	350.0	2.199E-06 (5.585E-05)	7.31 (8.03)
.5064 (12.86)	362.0	2.095E-06 (5.321E-05)	7.58 (8.33)
.5226 (13.27)	370.0	2.256E-06 (5.731E-05)	7.75 (8.51)
.5425 (13.78)	378.0	2.752E-06 (6.990E-05)	7.96 (8.74)
.5602 (14.23)	384.0	2.766E-06 (7.026E-05)	8.14 (8.95)
.5848 (14.85)	394.0	2.878E-06 (7.311E-05)	8.41 (9.24)
.6070 (15.42)	401.0	3.697E-06 (9.390E-05)	8.66 (9.51)
.6342 (16.11)	407.5	3.811E-06 (9.681E-05)	8.97 (9.85)
.6550 (16.64)	413.5	3.248E-06 (8.708E-05)	9.21 (10.12)
.6740 (17.12)	419.1	3.664E-06 (9.307E-05)	9.44 (10.37)
.6952 (17.66)	424.5	4.209E-06 (1.069E-04)	9.70 (18.65)
.7185 (18.25)	429.7	5.391E-06 (1.369E-04)	9.99 (10.98)
.7337 (18.64)	432.3	5.886E-06 (1.495E-04)	10.19 (11.20)
.7605 (19.32)	436.8	6.143E-06 (1.560E-04)	10.55 (11.59)
.7838 (19.91)	440.5	6.256E-06 (1.589E-04)	10.88 (11.95)
.8148 (20.70)	445.5	6.968E-06 (1.770E-04)	11.33 (12.45)
.8363 (21.24)	448.4	6.810E-06 (1.730E-04)	11.66 (12.82)
.8526 (21.66)	451.0	7.865E-06 (1.998E-04)	11.93 (13.10)
.8761 (22.25)	453.5	9.364E-06 (2.378E-04)	12.32 (13.53)
.8957 (22.75)	455.6	9.683E-06 (2.460E-04)	12.66 (13.91)
.9147 (23.23)	457.5	1.071E-05 (2.721E-04)	13.00 (14.29)
.9340 (23.72)	459.2	1.165E-05 (2.960E-04)	13.37 (14.69)

TABLE 26. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		<u>Ti-10-4 (Continued)</u>	
.9531 (24.21)	460.8	1.100E-05 (2.794E-04)	13.75 (15.11)
.9692 (24.62)	462.4	1.159E-05 (2.943E-04)	14108 (15.47)
.9804 (24.90)	463.3	1.302E-05 (3.308E-04)	14.32 (15.74)
1.0044 (25.51)	465.0	1.448E-05 (3.678E-04)	14.86 (16.32)
1.0266 (26.08)	466.5	1.295E-05 (3.288E-04)	15.38 (16.90)
1.0423 (26.47)	467.9	2.545E-05 (6.465E-04)	15.77 (17.33)
1.0651 (27.05)	468.6	2.858E-05 (7.260E-04)	16.37 (17.99)
1.0802 (27.44)	469.2	2.301E-05 (5.845E-04)	16.79 (18.45)
1.0980 (27.89)	470.1	3.509E-05 (8.913E-04)	17.31 (19.02)
1.1309 (28.72)	470.8	3.578E-05 (9.089E-04)	18.34 (20.15)
1.1466 (29.12)	471.4	8.267E-05 (2.100E-03)	18.87 (20.73)
1.1669 (29.64)	471.6	8.550E-05 (2.172E-03)	19.59 (21.53)
1.1808 (30.00)	471.8	6.175E-05 (1.568E-03)	20.12 (22.10)
1.1916 (30.27)	472.0	6.875E-05 (1.746E-03)	20.54 (22.57)
1.2083 (30.69)	472.2	3.250E-05 (8.255E-04)	21.22 (23.32)
1.2090 (30.71)	472.3	9.750E-05 (2.477E-03)	21.25 (23.36)
1.2278 (31.19)	472.4	1.035E-04 (2.629E-03)	22.08 (24.26)
1.2297 (31.23)	472.5	9.550E-05 (2.426E-03)	221.6 (24.35)
1.2469 (31.67)	472.6		22.97 (25.24)
		<u>Ti-10-5</u>	
.1312 (3.33)	20.0		3.97 (4.36)
.1523 (3.87)	60.0	5.438E-07 (1.381E-05)	4.17 (4.58)
.1747 (4.44)	100.0	4.833E-07 (1.228E-05)	4.38 (4.82)
.1968 (5.00)	160.0	4.248E-07 (1.079E-05)	4.59 (5.85)
.2153 (5.47)	200.0	5.163E-07 (1.311E-05)	4.77 (5.24)
.2381 (6.05)	240.0	9.433E-07 (2.396E-05)	4.98 (5.47)
.2607 (6.62)	260.0	1.014E-06 (2.577E-05)	5.20 (5.71)
.2909 (7.37)	298.0	7.659E-07 (1.945E-05)	5.48 (6.02)
.3103 (7.88)	324.0	9.132E-07 (2.320E-05)	5.67 (6.23)
.3335 (8.47)	346.0	1.146E-06 (2.911E-05)	5.89 (6.47)
.3661 (9.30)	372.0	1.054E-06 (2.678E-05)	6.20 (6.81)
.3810 (9.68)	388.0	9.549E-07 (2.426E-05)	6.34 (6.97)
.4013 (10.19)	408.6	1.263E-06 (3.200E-05)	6.54 (7.19)
.4200 (10.67)	421.6	1.390E-06 (3.530E-05)	6.72 (7.39)
.4468 (11.35)	442.0	1.818E-06 (4.618E-05)	6.99 (7.68)
.4771 (12.12)	456.0	2.188E006 (5.558E-05)	7.29 (8.01)
.5036 (12.79)	468.0	2.381E-06 (6.049E-05)	7.56 (8.31)
.5262 (13.36)	477.0	2.379E-06 (6.044E-05)	7.79 (8.56)
.5443 (13.82)	485.0	2.717E-06 (6.901E-05)	7.98 (8.77)
.5661 (14.38)	492.0	2.990E-06 (7.594E-05)	8.22 (9.03)
.5834 (14.82)	498.0	3.006E-06 (7.634E-05)	8.40 (9.23)

TABLE 26. (Concluded)

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		Ti-10-5 (Continued)	
.5926 (15.05)	501.0	3.089E-06 (7.846E-05)	8.50 (9.35)
.6114 (15.53)	507.0	3.080E-06 (7.823E-05)	8.71 (9.58)
.6384 (16.22)	516.0	3.500E-06 (8.890E-05)	9.02 (9.92)
.6614 (16.80)	522.0	3.846E-06 (9.768E-05)	9.29 (10.21)
.6830 (17.35)	527.6	4.260E-06 (1.082E-04)	9.56 (10.50)
.7081 (17.98)	533.0	4.940E-06 (1.255E-04)	9.87 (10.85)
.7347 (18.66)	538.1	5.198E-06 (1.320E-04)	10.21 (11.22)
.7575 (19.24)	542.5	5.157E-06 (1.310E-04)	10.52 (11.56)
.7862 (19.97)	548.1	6.178E-06 (1.569E-04)	10.93 (12.01)
.8194 (20.81)	552.8	7.141E-06 (1.814E-04)	11.42 (12.55)
.8388 (21.30)	555.5	8.397E-06 (2.133E-04)	11.72 (12.88)
.8626 (21.91	558.0	1.022E-05 (2.596E-04)	12.11 (13.30)
.8853 (22.49)	560.1	9.984E-06 (2.536E-04)	12.49 (13.73)
.9086 (23.08)	562.7	1.112E-05 (2.824E-04)	12.91 (14.19)
.9313 (23.66)	564.5	1.104E-05 (2.804E-04)	13.34 (14.66)
.9577 (24.32)	567.7	1.196E-05 (3.037E-04)	13.86 (15.23)
.9798 (24.89)	569.3	1.525E-05 (3.874E-04)	14.33 (15.75)
1.0065 (25.56)	570.9	1.775E-05 (4.509E-04)	14.93 (16.41)
1.0307 (26.18)	572.2	1.856E-05 (4.715E-04)	15.51 (17.04)
1.0603 (26.93)	573.8	2.065E-05 (5.246E-04)	16.27 (17.88)
1.0823 (27.49)	574.8	1.961E-05 (4.982E-04)	16.88 (18.55)
1.1024 (28.00)	576.0	2.455E-05 (6.236E-04)	17.48 (19.20)
1.1262 (28.60)	576.8	4.508E-05 (1.145E-03)	18.22 (20.03)
1.1473 (29.14)	577.2	4.412E-05 (1.121E-03)	18.93 (20.81)
1.1660 (29.62)	577.8	7.817E-05 (1.985E-03)	19.60 (21.54)
1.1965 (30.39)	578.1	6.437E-05 (1.635E-03)	20.79 (22.84)
1.2044 (30.59)	578.3	6.101E-05 (1.550E-03)	21.11 (23.20)
1.2618 (32.05)	578.8	1.791E-04 (4.550E-03)	23.77 (26.12)
1.2810 (32.54)	578.9		24.79 (27.24)

Specimen Identification	Thickness, B, inch (mm)	Width, W, inch (mm)
Ti-10-3	0.5010 (12.72)	1.999 (50.77)
Ti-10-4	0.5012 (12.73)	1.9975 (50.74)
Ti-10-5	0.5013 (12.73)	1.9956 (60.69)

TABLE 27. FATIGUE-CRACK-PROPAGATION DATA FOR STA Ti-10V-2Fe-3Al PANCAKE AT 600 F (589 K) - L-T SPECIMEN

a, inches	(mm)	N, cycles x 10^3	da/dN, inch/cycle	(mm/cycle)	ΔK, ksi$\sqrt{in}$	(MPa$\sqrt{m}$)
			Ti-10-2			
.1400	(3.56)	20.0			3.38	(3.71)
.1679	(4.26)	90.0	4.377E-07	(1.112E-05)	3.60	(3.96)
.1863	(4.73)	130.0	4.829E-07	(1.227E-05)	3.74	(4.11)
.2286	(5.81)	210.0	5.446E-07	(1.383E-05)	4.08	(4.48)
.2507	(6.37)	250.0	5.600E-07	(1.422E-05)	4.25	(4.67)
.2734	(6.94)	290.0	6.458E-07	(1.640E-05)	4.43	(4.87)
.2984	(7.58)	325.0	6.940E-07	(1.763E-05)	4.63	(5.09)
.3187	(8.10)	355.0	5.950E-07	(1.511E-05)	4.79	(5.26)
.3341	(8.49)	385.0	6.467E-07	(1.643E-05)	4.91	(5.40)
.3575	(9.08)	415.0	8.000E-07	(2.032E-05)	5.10	(5.68)
.3821	(9.70)	445.0	7.700E-07	(1.956E-05)	5.30	(5.82)
.4037	(10.25)	475.0	8.924E-07	(2.267E-05)	5.47	(6.81)
.4296	(10.91)	500.0	9.327E-07	(2.369E-05)	5.68	(6.24)
.4466	(11.34)	520.0	1.118E-06	(2.838E-05)	5.82	(6.40)
.4743	(12.05)	540.0	1.420E-06	(3.607E-05)	6.05	(6.65)
.5034	(12.79)	560.0	1.322E-06	(3.357E-05)	6.30	(6.92)
.5206	(13.22)	574.0	1.241E-06	(3.151E-05)	6.45	(7.09)
.5394	(13.70)	589.0	1.333E-06	(3.385E-05)	6.61	(7.27)
.5504	(13.98)	597.0	1.560E-06	(3.962E-05)	6.71	(7.37)
.5790	(14.71)	612.0	1.556E-06	(3.952E-05)	6.97	(7.66)
.5943	(15.10)	624.0	1.501E-06	(3.813E-05)	7.11	(7.81)
.6112	(15.52)	634.0	1.765E-06	(4.482E-05)	7.26	(7.98)
.6354	(16.14)	647.0	2.136E-06	(5.426E-05)	7.50	(8.24)
.6700	(17.02)	661.2	3.245E-06	(8.241E-05)	7.84	(8.61)
.6955	(17.66)	668.2	3.685E-06	(9.360E-05)	8.10	(8.90)
.7167	(18.20)	673.9	3.131E-06	(7.953E-05)	8.32	(9.14)
.7306	(18.56)	679.3	3.370E-06	(8.561E-05)	8.47	(9.31)
.7531	(19.13)	684.7	4.498E-06	(1.142E-04)	8.72	(9.59)
.7761	(19.71)	689.5	4.687E-06	(1.191E-04)	8.99	(9.88)
.7945	(20.18)	693.5	4.667E-06	(1.186E-04)	9.21	(10.12)
.8120	(20.62)	697.2	4.870E-06	(1.237E-04)	9.43	(10.36)
.8394	(21.32)	702.6	8.488E-06	(2.156E-04)	9.78	(10.75)
.8546	(21.71)	704.2	8.217E-06	(2.087E-04)	9.99	(10.97)
.8697	(22.09)	706.6	9.957E-06	(2.529E-04)	10.20	(11.20)
.8825	(22.42)	707.7	1.061E-05	(2.694E-04)	10.38	(11.40)
.9059	(23.01)	710.7	4.710E-06	(1.196E-04)	10.73	(11.79)
.9108	(23.13)	712.3	5.217E-06	(1.325E-04)	10.80	(11.87)
.9347	(23.74)	715.0	9.841E-06	(2.500E-04)	11.18	(12.28)
.9536	(24.22)	716.8	9.353E-06	(2.376E-04)	11.49	(12.63)
.9770	(24.82)	720.0	9.375E-06	(2.381E-04)	11.90	(13.08)
.9948	(25.27)	721.7	1.290E-05	(3.277E-04)	12.23	(13.44)
1.0340	(26.26)	724.1	1.441E-05	(3.660E-04)	13.01	(14.29)
1.0526	(26.74)	725.5	1.308E-05	(3.321E-04)	13.41	(14.73)

TABLE 27. (Continued)

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		Ti-10-2 (Continued)	
1.0794 (27.42)	727.6	1.508E-05 (3.831E-04)	14.02 (15.40)
1.0905 (27.70)	728.3	1.511E-05 (3.837E-04)	14.28 (15.70)
1.1175 (28.38)	730.4	1.821E-05 (4.626E-04)	14.97 (16.45)
1.1315 (28.74)	731.1	3.164E-05 (8.037E-04)	15.35 (16.87)
1.1618 (29.51)	731.8	3.811E-05 (9.679E-04)	16.23 (17.83)
1.1820 (30.02)	732.4	4.647E-05 (1.180E-03)	16.86 (18.53)
1.2040 (30.58)	732.8	4.473E-05 (1.136E-03)	17.60 (19.34)
1.2216 (31.03)	733.4	4.133E-05 (1.050E-03)	18.24 (20.04)
1.2536 (31.84)	734.0	6.133E-05 (1.558E-03)	19.50 (21.42)
1.2664 (32.17)	734.2		20.04 (22.02)
		Ti-10-6	
.1550 (3.94)	40.0		3.50 (3.84)
.1765 (4.48)	75.0	6.533E-07 (1.659E-05)	3.67 (4.83)
.1971 (5.01)	105.0	6.400E-07 (1.626E-05)	3.83 (4.21)
.2149 (5.46)	135.0	6.583E-07 (1.672E-05)	3.97 (4.36)
.2366 (6.01)	165.0	7.867E-07 (1.998E-05)	4.14 (4.55)
.2621 (6.66)	195.0	8.005E-07 (2.033E-05)	4.34 (4.77)
.2818 (7.16)	221.0	8.124E-07 (2.064E-05)	4.50 (4.94)
.3016 (7.66)	244.0	9.401E-07 (2.388E-05)	4.65 (5.11)
.3329 (8.46)	274.0	1.038E-06 (2.637E-05)	4.90 (5.39)
.3536 (8.98)	294.0	1.088E-06 (2.762E-05)	5.07 (5.57)
.3764 (9.56)	314.0	1.154E-06 (2.931E-05)	5.25 (5.77)
.3974 (10.09)	332.0	1.232E-06 (3.130E-05)	5.42 (5.95)
.4167 (10.58)	347.0	1.541E-06 (3.914E-05)	5.58 (6.13)
.4416 (11.22)	361.0	1.732E-06 (4.399E-05)	5.78 (6.35)
.4619 (11.73)	373.0	1.704E-06 (4.329E-05)	5.95 (6.54)
.4825 (12.26)	385.0	1.877E-06 (4.767E-05)	6.12 (6.73)
.5026 (12.77)	395.0	2.190E-06 (5.563E-05)	6.29 (6.91)
.5263 (13.37)	405.0	2.200E-06 (5.588E-05)	6.50 (7.14)
.5466 (13.88)	415.0	2.517E-06 (6.392E-05)	6.67 (7.33)
.5604 (14.23)	420.0	2.723E-06 (6.918E-05)	6.80 (7.47)
.5638 (14.83)	428.8	2.651E-06 (6.733E-05)	7.01 (7.70)
.6060 (15.39)	437.2	2.888E-06 (7.335E-05)	7.21 (7.93)
.6303 (16.01)	445.0	3.394E-06 (8.621E-05)	7.44 (8.18)
.6562 (16.67)	452.1	3.834E-06 (9.740E-05)	7.69 (8.46)
.6814 (17.31)	458.4	4.146E-06 (1.053E-04)	7.95 (8.73)
.7049 (17.90)	463.9	4.578E-06 (1.163E-04)	8.19 (9.00)
.7402 (18.80)	471.0	4.541E-06 (1.153E-04)	8.57 (9.42)
.7578 (19.25)	475.1	5.029E-06 (1.277E-04)	8.77 (9.64)
.7795 (19,80)	478.9	6.069E-06 (1.542E-04)	9.03 (9.92)
.8019 (20.37)	482.4	5.102E-06 (1.296E-04)	9.30 (10.22)
.8147 (20.69)	485.7	9.811E-06 (2.492E-04)	9.46 (10.39)
.8350 (21.21)	487.3	1.097E-05 (2.786E-04)	9.72 (10.68)

TABLE 27. (Concluded)

a, inches (mm)	N, cycles x 10^3	da/dN, inch/cycle (mm/cycle)	ΔK, ksi$\sqrt{in}$ (MPa$\sqrt{m}$)
		Ti-10-6 (Continued)	
.8557 (21.73)	489.8	8.397E-06 (2.133E-04)	9.99 (10.98)
.8744 (22.21)	492.0	1.018E-05 (2.586E-04)	10.26 (11.27)
.8965 (22.77)	493.9	1.065E-05 (2.705E-04)	10.58 (11.62)
.9140 (23,22)	495.7	1.094E-05 (2.780E-04)	10.84 (11.91)
.9244 (23.48)	496.6	1.074E-05 (2.728E-04)	11.00 (12.09)
.9408 (23.40)	498.4	1.042E-05 (2.646E-04)	11.27 (12.38)
.9619 (24.43)	500.2	1.233E-05 (3.133E-04)	11.63 (12.78)
.9852 (25.02)	502.0	1.500E-05 (3.810E-04)	12.04 (13.23)
1.0140 (25.76)	503.7	1.623E-05 (4.123E-04)	12.59 (13.83)
1.0344 (26.27)	505.0	1.743E-05 (4.428E-04)	13.00 (14.29)
1.0552 (26.80)	506.1	2.006E-05 (5.094E-04)	13.45 (14.78)
1.0763 (27.34)	507.1	2.056E-05 (5.222E-04)	13.93 (15.30)
1.0924 (27.75)	507.9	2.319E-05 (5.890E-04)	14.31 (15.73)
1.1134 (28.28)	508.7	2.594E-05 (6.588E-04)	14.84 (16.31)
1.1339 (28.80)	509.5	3.175E-05 (8.064E-04)	15.40 (16.92)
1.1733 (29.80)	510.5	4.071E-05 (1.034E-03)	16.56 (18.20)
1.1982 (30.43)	511.1	4.135E-05 (1.050E-03)	17.38 (19.10)
1.2147 (30.85)	511.5	4.688E-05 (1.191E-03)	17.96 (19.73)
1.2357 (31.34)	511.9	6.517E-05 (1.655E-03)	18.74 (20.60)
1.2500 (31.74)	512.1	7.050E-05 (1.791E-03)	19.31 (21.22)
1.2707 (32.28)	512.4	8.340E-05 (2.118E-03)	20.19 (22.19)
1.2893 (32.75)	512.6	1.077E-04 (2.735E-03)	21.04 (23.12)
1.3008 (33.04)	512.7	1.320E-04 (3.353E-03)	21.60 (23.73)
1.3157 (33.42)	512.8		22.35 (24.56)

Specimen Identification	Thickness, B, inch (mm)	Width, W, inch (mm)
Ti-10-2	0.5013 (12.73)	1.9947 (50.66)
Ti-10-6	0.5011 (12.73)	1.996 (50.70)

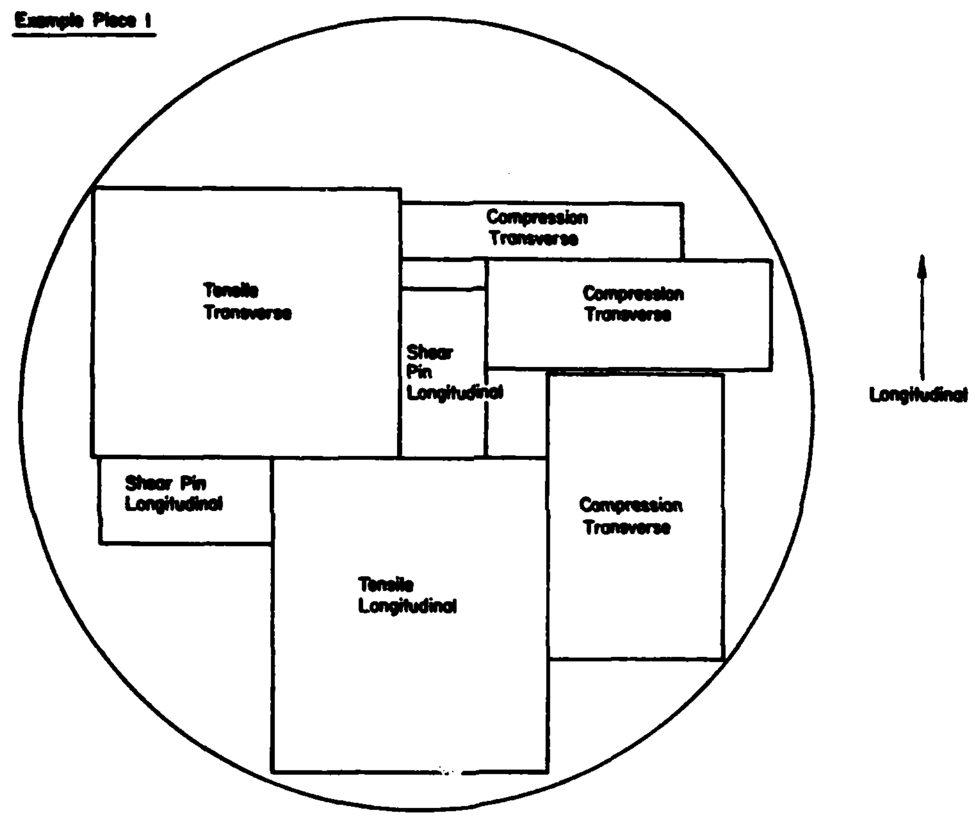


Figure 28a. Specimen location for Ti-10V-2Fe-3Al isothermally forged pancake.

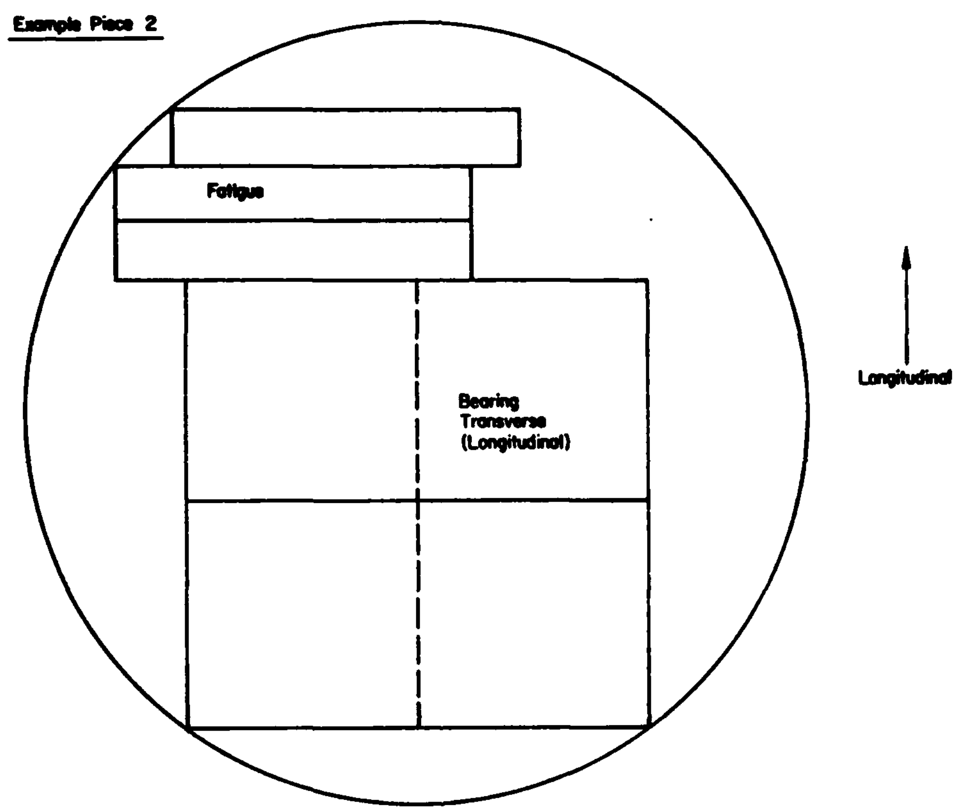


Figure 28b. Specimen location for Ti-10V-2Fe-3Al isothermally forged pancake.

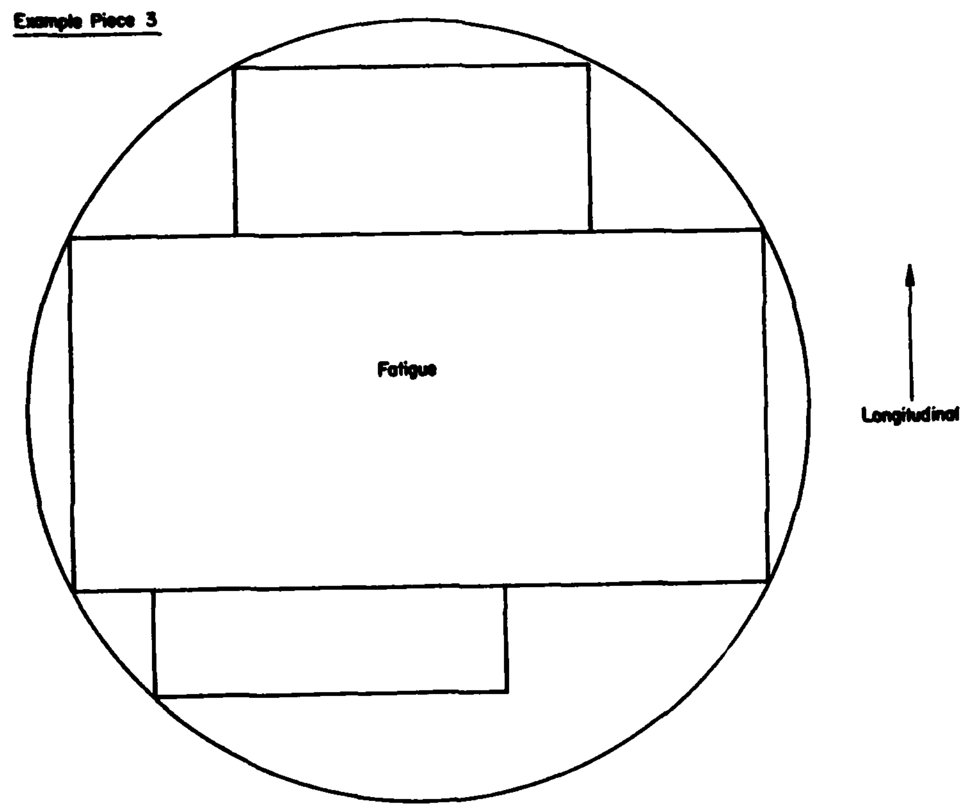


Figure 28c. Specimen location for Ti-10V-2Fe-3Al isothermally forged pancake.

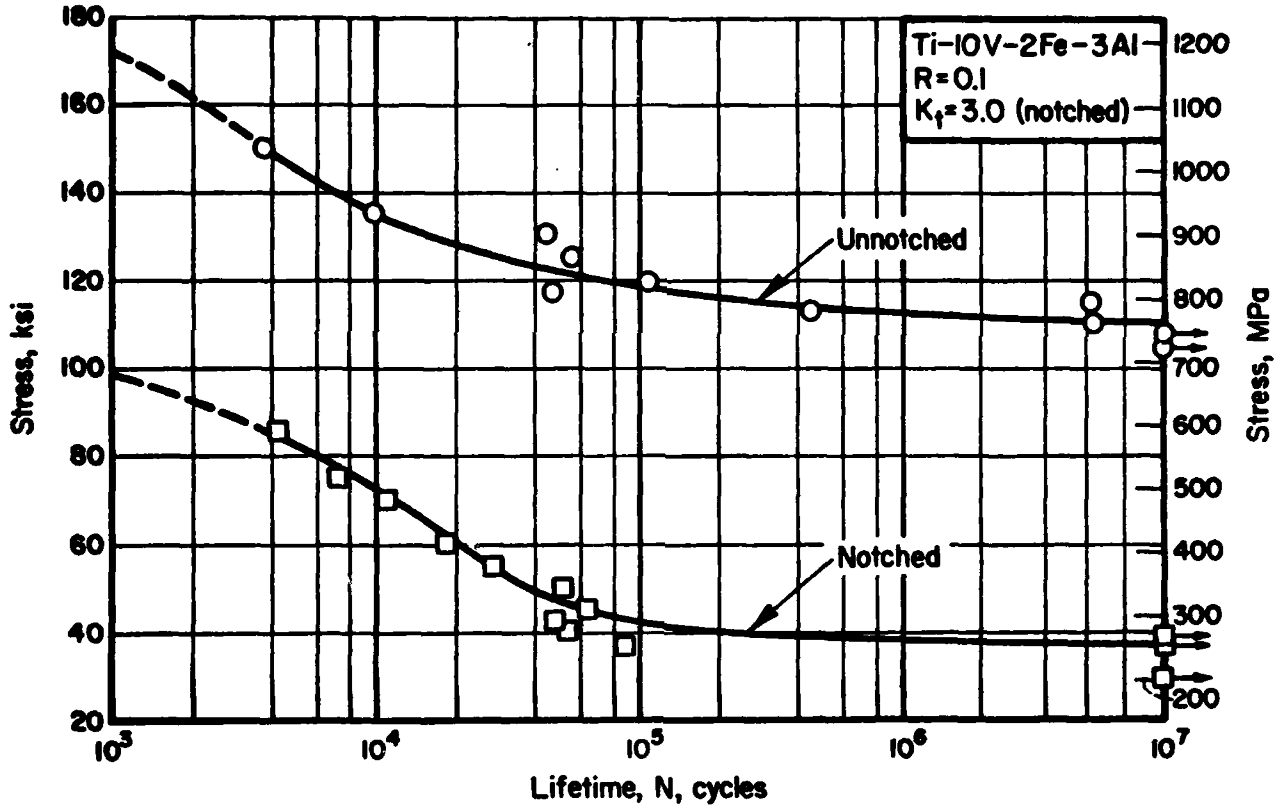


Figure 29. Axial load fatigue behavior of unnotched and notched (K_t = 3.0), STA, Ti-10V-2Fe-3Al pancake at room temperature, long transverse.

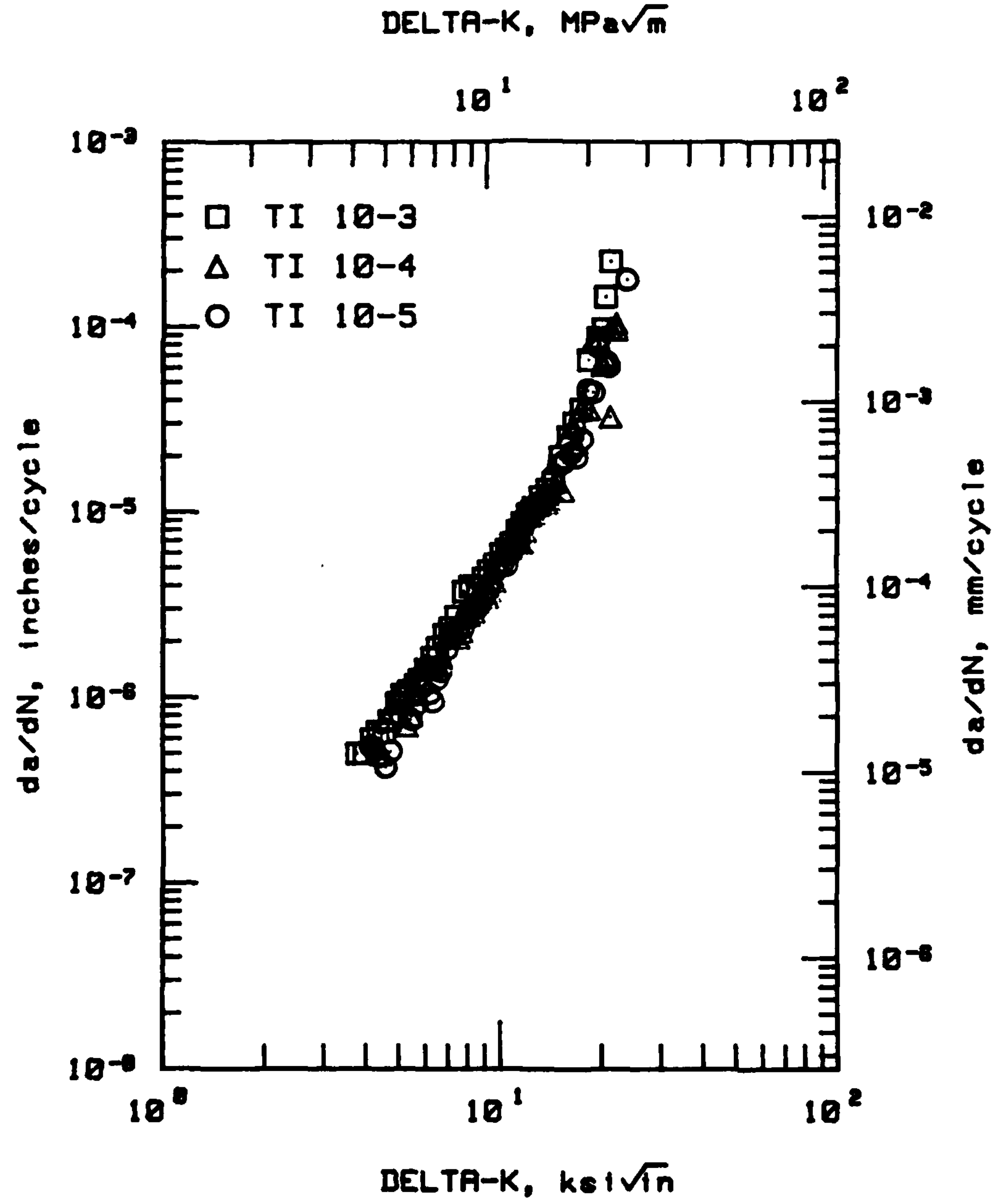


Figure 30. Plot of da/dN versus delta K for Ti-10V-2Fe-3Al pancake.

Lab Air
Room Temperature
R = 0.1
Frequency = 30 Hz
Specimen Orientation = L-T

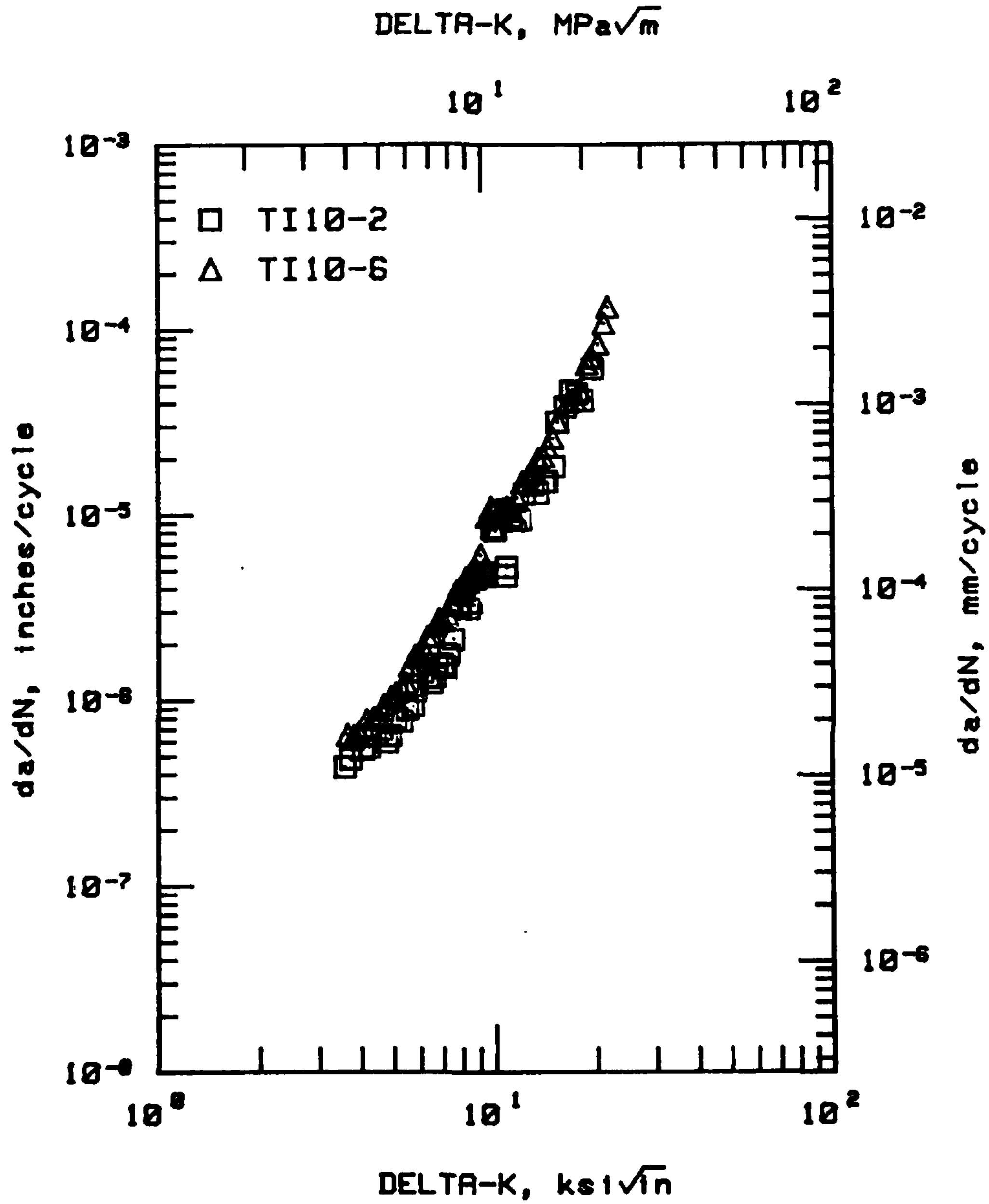


Figure 31. Plot of da/dN versus delta K for Ti-10V-2Fe-3Al pancake.

Lab Air (Heated)
600 F (589 K)
R = 0.1
Frequency = 30 Hz
Specimen Orientation = L-T

APPENDIX A

DATA SHEETS

MECHANICAL-PROPERTY DATA
Ti-6Al-4V ALLOY

POWDER METALLURGY PRODUCT
CHIP

Issued by

Air Force Wright Aeronautical Laboratory
Materials Laboratory
Wright-Patterson Air Force Base, Ohio

May 1981

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-80-C-5168
77

Ti-6Al-4V Alloy (CHIP)

Material Description

This Ti-6Al-4V alloy, a powder metallurgy product from Dynamet Technology, was received as sixty 5/8" diameter x 5" bars, seven 0.125" x 2" x 12" strips, and nine 3/4" x 3" x 3" blanks.

The chemical composition of this lot is as follows:

Chemical Composition	Percent Weight
Aluminum	5.70
Vanadium	4.22
Carbon	0.024
Hydrogen	0.0013
Nickel	0.0112
Oxygen	0.19
Others	0.043
Titanium	Balance.

Processing and Heat Treating

The Ti-6Al-4V alloy was received in the "CHIP"ed condition. "CHIP" (Cold Hot Isostatically Pressed) processing means the material was cold isostatically pressed at 60,000 psi (413.7 MPa), vacuum sintered at 2250 F (1505 K) for 3 hours and furnace cooled, and hot isostatically pressed at 15,000 psi (103.4 MPa) at 1650 F (1172 K) to achieve the desired density and mechanical properties.

Results of this evaluation show slightly lower strength values than for the wrought annealed material. The tensile and compression results were slightly lower while the bearing and shear results were slightly higher.

Ti-6Al-4V

Condition: CHIP[(a)]

Properties	RT	(RT)	400	(477)	800	(700)
	Temperature, F (K)					
Tension						
TUS, ksi (MPa)	127.4	(878.4)	96.0	(661.9)	76.6	(528.2)
TYS, ksi (MPa)	115.8	(798.4)	83.2	(573.7)	60.4	(416.5)
RA, percent	12.2	(12.2)	16.1	(16.1)	26.7	(26.7)
e, percent in 1 in. (25.4 mm)	6.7	(6.7)	7.0	(7.0)	10.8	(10.8)
E, 10^3 ksi (GPa)	16.9	(116.5)	15.7	(108.3)	13.6	(93.8)
Compression						
CYS, ksi (MPa)	123.8	(853.6)	83.3	(574.4)	61.0	(420.6)
E_c, 10^3 ksi (GPa)	15.9	(109.6)	15.0	(103.4)	13.2	(91.0)
Shear						
SUS, ksi (MPa)	88.8	(612.3)	71.3	(491.5)	55.3	(381.4)
Bearing						
e/D = 1.5						
BUS, ksi (MPa)	212.6	(1465.7)	154.6	(1065.8)	151.1	(1041.8)
BYS, ksi (MPa)	209.7	(1446.1)	142.8	(984.3)	120.6	(831.4)
e/D = 2.0						
BUS, ksi (MPa)	262.0	(1806.0)	195.4	(1347.6)	192.6	(1328.3)
BYS, ksi (MPa)	242.0	(1669.0)	173.5	(1196.1)	140.7	(970.3)
Fracture Toughness						
K_{IC}, ksi$\sqrt{\text{in.}}$ (MPa·$m^{1/2}$)	36.7[(b)]	(40.4)	NA[(c)]		NA	
Axial Fatigue						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	124	(854)	NA		73	(503)
10^5 cycles, ksi (MPa)	64[(d)]	(441)			48[(d)]	(331)
10^7 cycles, ksi (MPa)	45[(d)]	(310)			35[(d)]	(241)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	(e)		NA		62[(d)]	(427)
10^5 cycles, ksi (MPa)	34	(234)			25	(172)
10^7 cycles, ksi (MPa)	19	(131)			15	(103)

Ti-6Al-4V (Continued)

Properties	Temperature, F (K)					
	RT	(RT)	400	(477)	800	(700)
Creep						
0.2% plastic deformation, 100 hr, ksi (MPa)	NA		NA		47.5	(327.5)
0.2% plastic deformation, 1000 1000 hr, ksi (MPa)	NA		NA		34.0	(234.4)
Stress Rupture						
Rupture, 100 hr, ksi (MPa)	NA		NA		50.0	(344.7)
Rupture, 1000 hr, ksi (MPa)	NA		NA		42.1	(290.3)

Stress Corrosion[f]

K_{ISCC} = 15 ksi$\sqrt{\text{in.}}$ (16.5 MPa$\cdot$m$^{1/2}$)

Coefficient of Thermal Expansion

6.0 x 10^{-6} in./in./F (70 - 800 F) [10.8 x 10^{-6} m/(m·k) (295 - 700 K)]

Density

0.159 lb./in.^{3} (4.41 g/cm^3)

(a) Cold isostatically pressed, vacuum sintered and hot isostatically pressed. Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) K_{IC} is valid as per ASTM E399.

(c) NA, not applicable.

(d) Estimated.

(e) Insufficient tests to estimate.

(f) This value is an approximate determination of K_{ISCC} at 10^{-8} in./sec. (25.4 x 10^{-8} mm/sec.). The increasing K tests lasted an average of 3 days and were conducted at 75 F (297 K) in 3-1/2% NaCl. Compact-tension-type specimens were used.

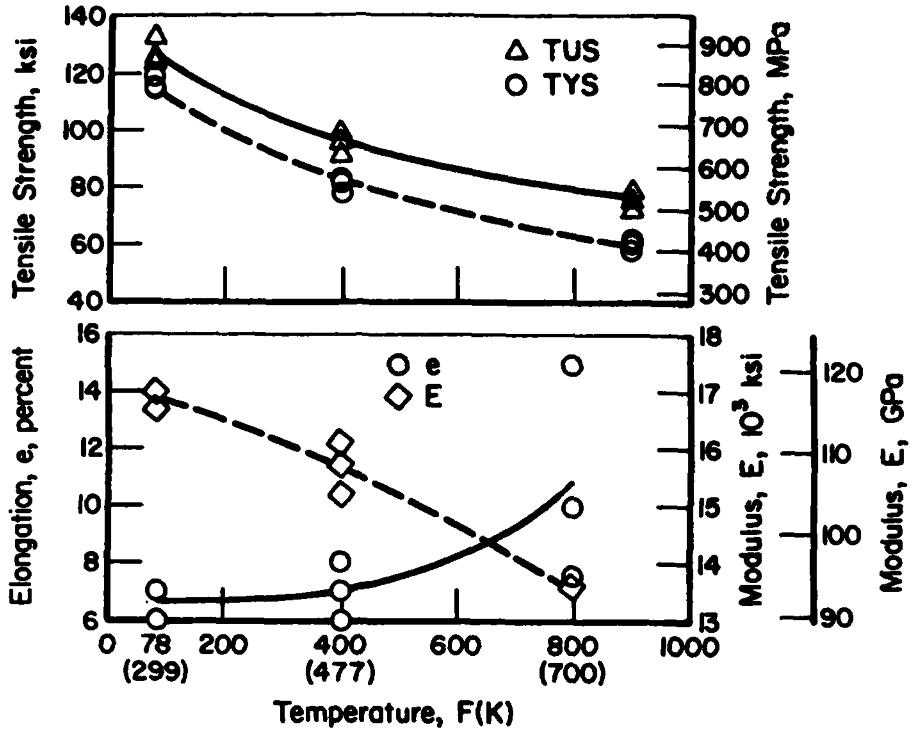


Figure 1. Effect of temperature on the tensile properties of Ti-6Al-4V (CHIP) Alloy.

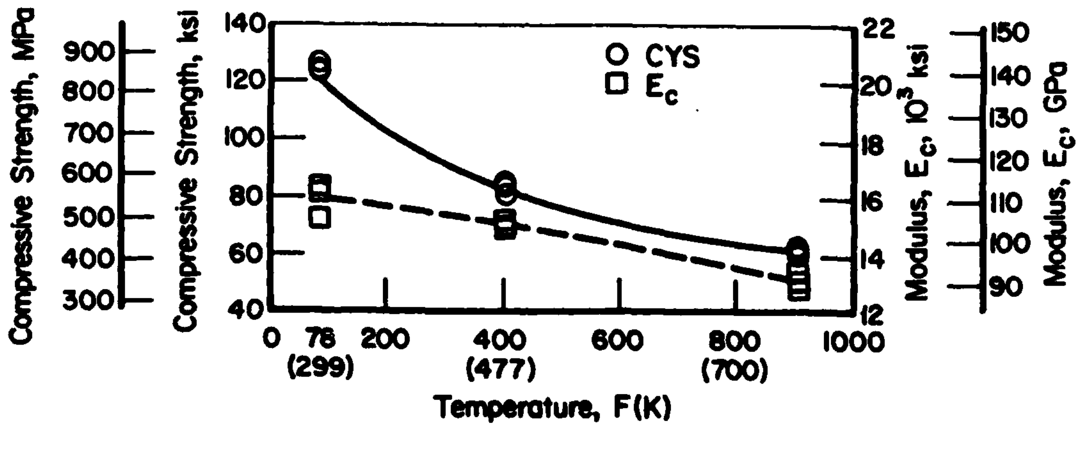


Figure 2. Effect of temperature on the compressive properties of Ti-6Al-4V (CHIP) Alloy.

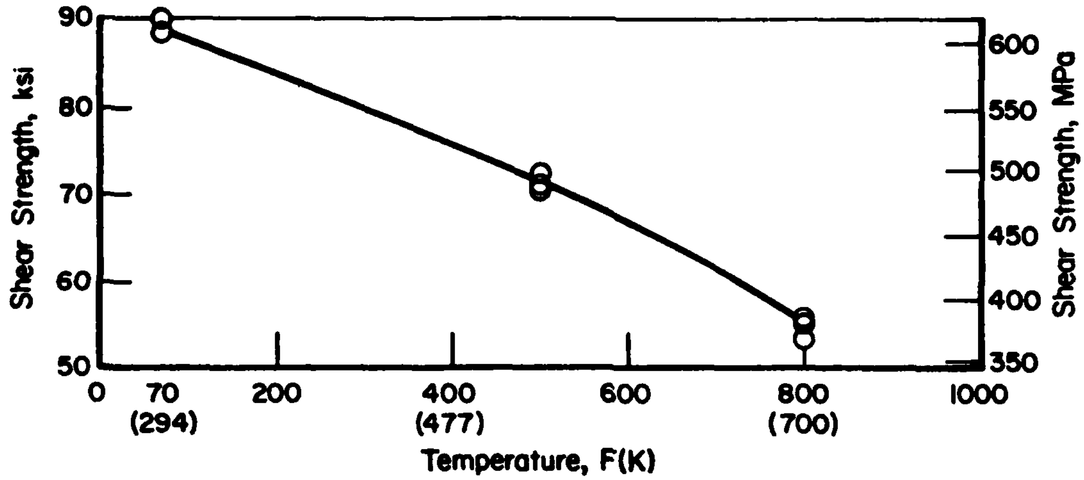


Figure 3. Effect of temperature on the pin shear properties of Ti-6Al-4V (CHIP) Alloy.

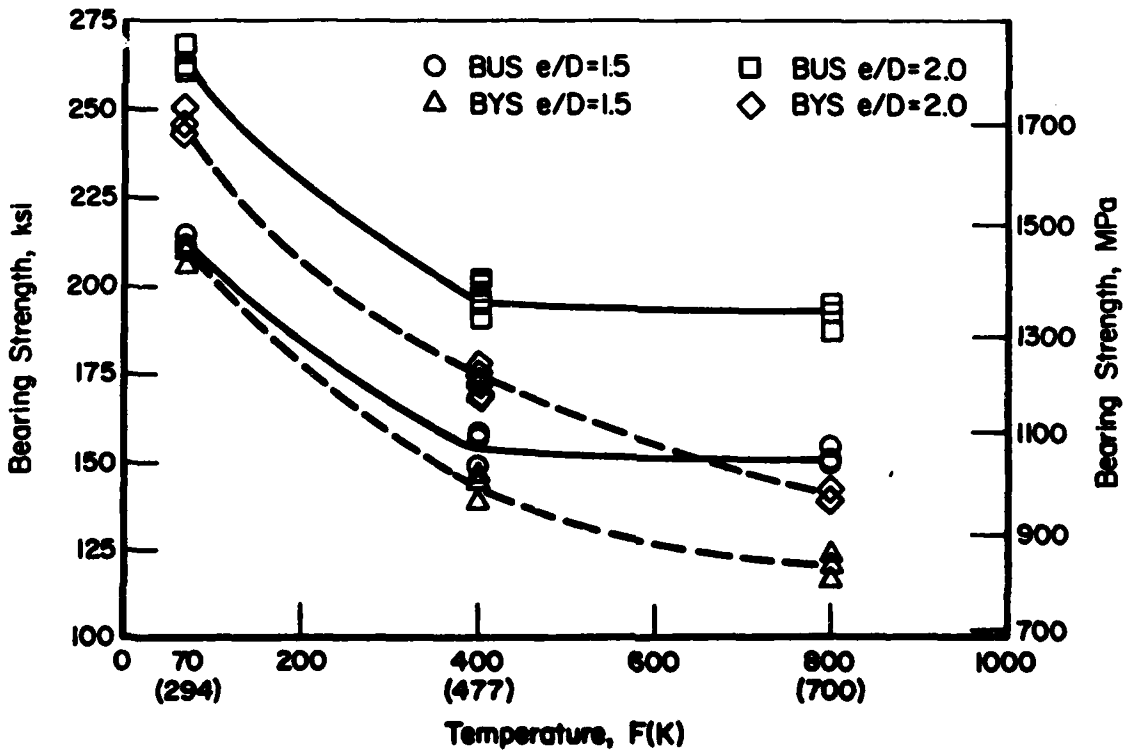


Figure 4. Effect of temperature on the bearing properties of Ti-6Al-4V (CHIP) Alloy.

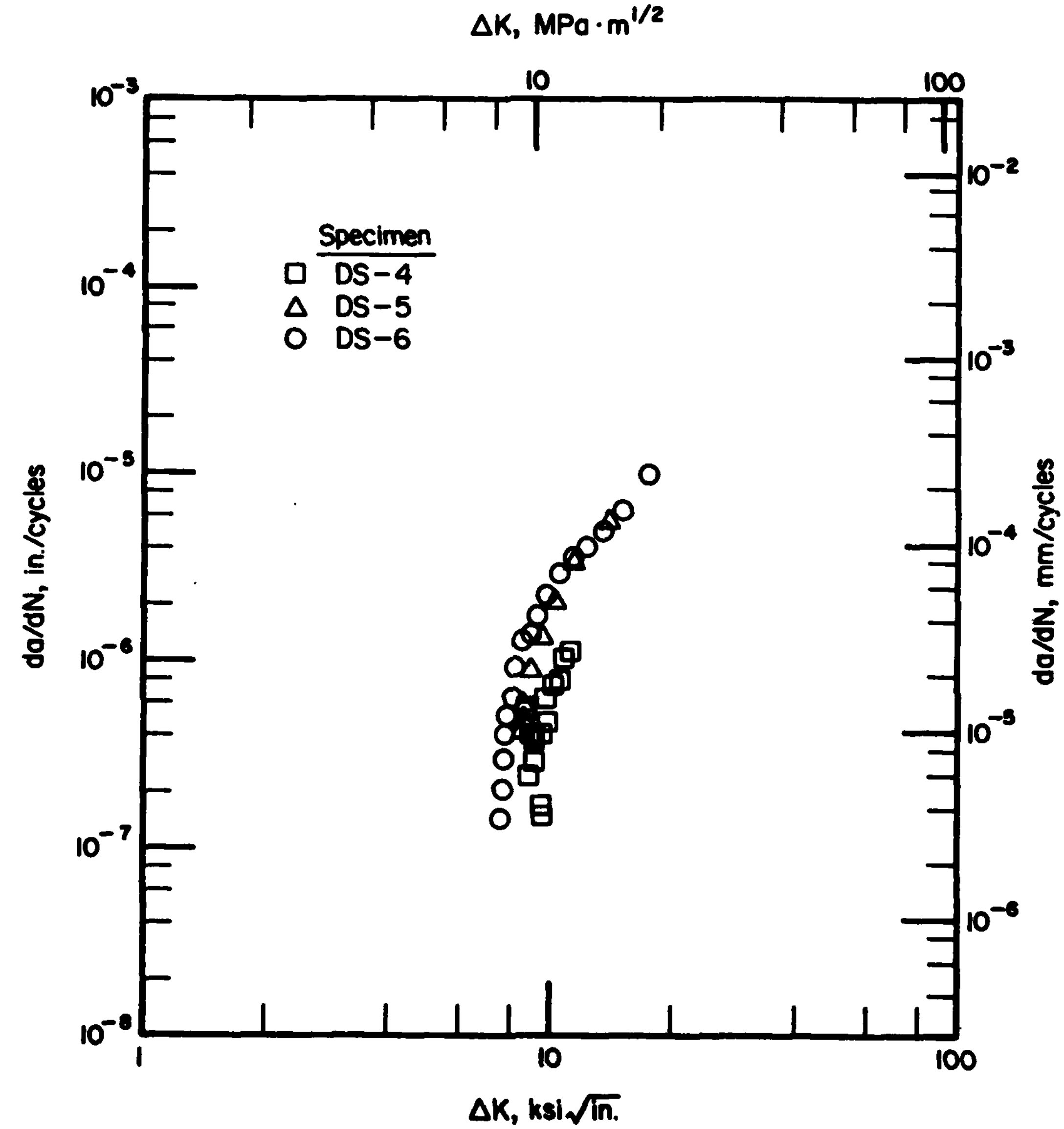


Figure 5. da/dN versus delta K for Ti-6Al-4V (CHIP) Alloy.

Lab Air
R = 0.1
Frequency = 20 Hz

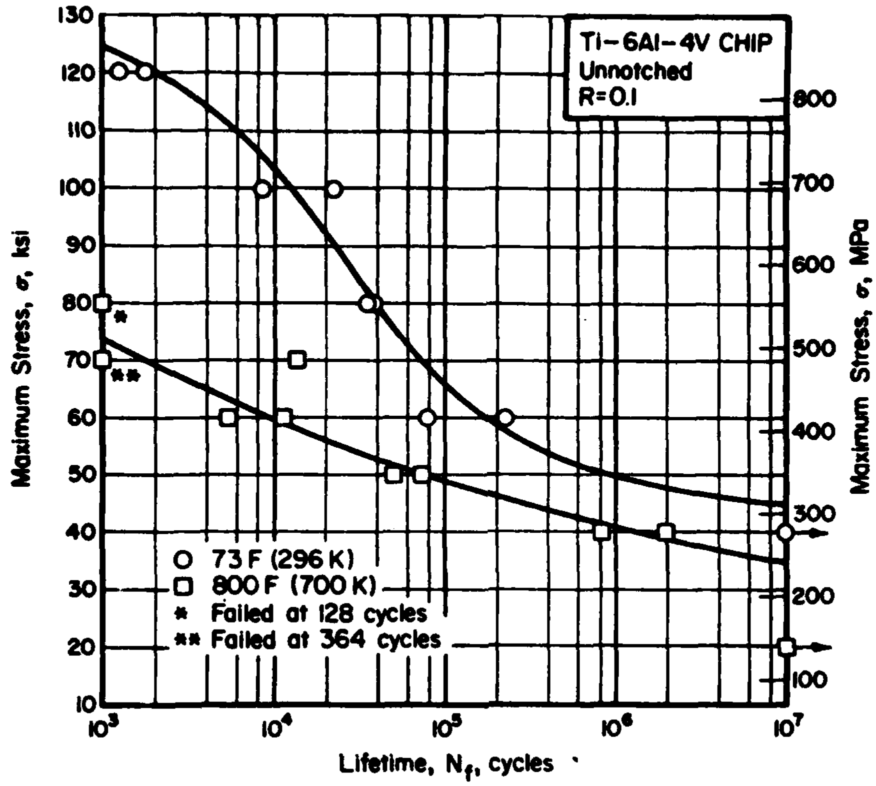


Figure 6. Axial load fatigue behavior of unnotched Ti-6Al-4V (CHIP) Alloy.

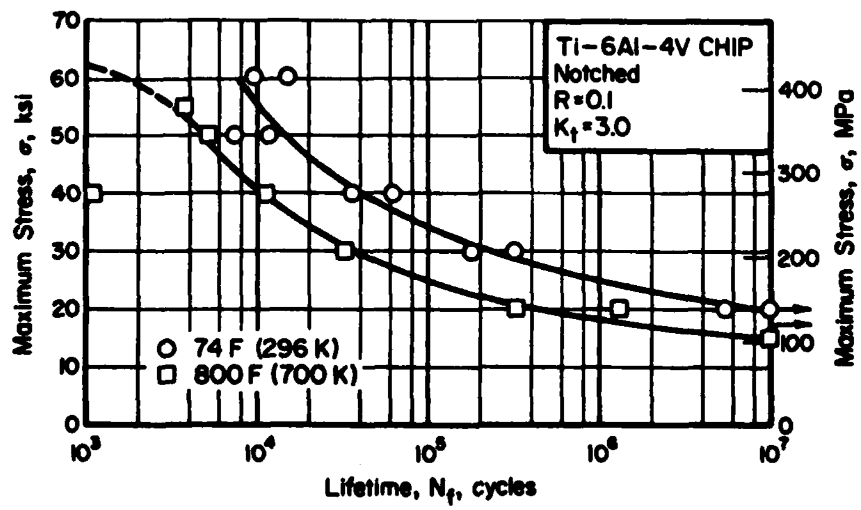


Figure 7. Axial load fatigue behavior of notched (k_t = 3.0) Ti-6Al-4V (CHIP) Alloy.

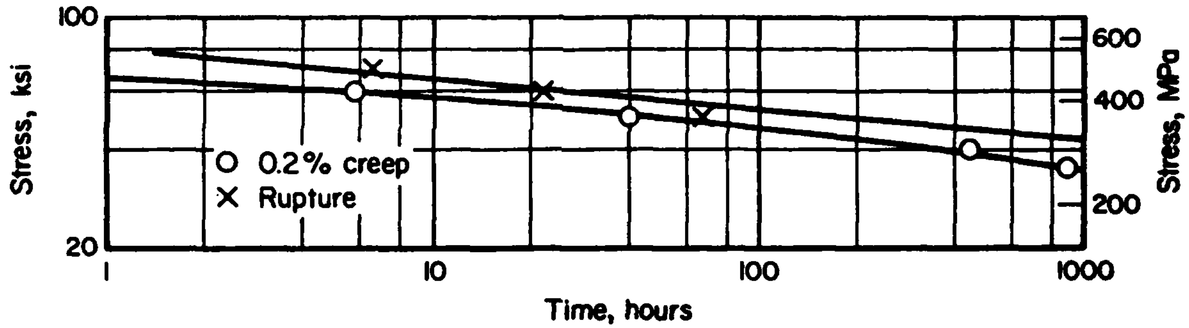


Figure 8. Stress-rupture and plastic deformation curves for annealed Ti-6Al-4V (CHIP) alloy.

MECHANICAL-PROPERTY DATA
CT 91-T7E69 ALUMINUM

POWDER METALLURGY PRODUCT

Issued by

Air Force Wright Aeronautical Laboratory
Materials Laboratory
Wright-Patterson Air Force Base, Ohio

September, 1981

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-80-C-5168

CT 91-T7E69 Aluminum

Material Description

CT 91-T7E69 aluminum alloy is a powder metallurgy product of Alcoa. The material was received as two 1½-inch thick x 4½-inch wide x 4-foot lengths.

The chemical composition of this lot is as follows:

Chemical Composition	Percent Weight
Silicon	0.15
Iron	0.20
Copper	1.20 - 2.00
Magnesium	2.20 - 3.00
Zinc	6.00 - 7.00
Cobalt	0.20 - 0.60
Other	0.15
Aluminum	Balance

Processing and Heat Treating

The CT 91 aluminum was received in the T7E69 condition. This temper was designed to have good static strength and fatigue resistance.

Results of these tests show higher tensile, shear, and fatigue data as compared to the T7E70 temper while giving lower fracture toughness values.

CT 91 Aluminum[a]

Condition: T7E69
Thickness: 1½ inch

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
Tension						
TUS, L, ksi (MPa)	89.6	(617.8)	74.5	(513.7)	59.2	(408.2)
TUS, T, ksi (MPa)	83.6	(576.4)	69.8	(481.3)	54.9	(379.5)
TYS, L, ksi (MPa)	83.0	(572.3)	72.9	(502.6)	57.5	(396.5)
TYS, T, ksi (MPa)	74.9	(516.4)	66.1	(455.8)	52.2	(359.9)
e, L, % in 2 in. (50.8 mm)	11.0		18.7		22.6	
e, T, % in 2 in. (50.8 mm)	11.7		17.2		21.5	
E, L, 10^3 ksi (GPa)	10.8	(74.5)	9.77	(67.4)	9.25	(63.8)
E, T, 10^3 ksi (GPa)	10.8	(74.5)	9.49	(65.4)	9.00	(62.1)
RA, L, Reduction in area, %	28.8		50.3		62.9	
RA, T, Reduction in area, %	29.0		41.3		52.1	
Compression						
CYS, L, ksi (MPa)	83.1	(573.0)	75.3	(519.2)	57.0	(393.0)
CYS, T, ksi (MPa)	80.8	(557.1)	72.0	(496.4)	57.0	(393.0)
E_c, L, 10^3 ksi (GPa)	10.6	(73.1)	9.3	(64.1)	8.7	(60.0)
E_c, T, 10^3 ksi (GPa)	10.0	(69.0)	9.8	(67.6)	8.5	(58.6)
Shear						
SUS, L, ksi (MPa)	52.8	(363.9)	44.6	(307.5)	35.3	(243.4)
SUS, T, ksi (MPa)	49.8	(343.2)	43.7	(301.3)	33.1	(228.2)
Bearing						
e/D = 1.5						
BUS, L, ksi (MPa)	135.1	(931.5)	111.0	(765.3)	86.00	(593.0)
BUS, T, ksi (MPa)	130.7	(901.2)	111.6	(769.5)	83.68	(577.0)
BYS, L, ksi (MPa)	107.6	(741.9)	95.9	(661.2)	78.09	(538.4)
BYS, T, ksi (MPa)	108.0	(744.7)	97.4	(671.6)	76.79	(529.5)
e/D = 2.0						
BUS, L, ksi (MPa)	171.7	(1183.9)	145.6	(1003.9)	108.3	(746.7)
BUS, T, ksi (MPa)	170.6	(1176.3)	146.6	(1010.8)	108.9	(750.9)
BYS, L, ksi (MPa)	126.0	(868.8)	111.8	(770.9)	89.1	(614.3)
BYS, T, ksi (MPa)	127.7	(880.5)	112.1	(772.9)	89.9	(619.9)

(Continued)

Properties	Temperature, F (K) RT	(RT)	250	(394)	350	(450)
Fracture Toughness						
K_{IC}, L-T, ksi$\sqrt{in.}$ (MPa·m$^{1/2}$)	24.2	(26.6)[b]	NA[c]		NA	
K_{IC}, T-L, ksi$\sqrt{in.}$ (MPa·m$^{1/2}$)	35.1	(38.6)	NA		NA	
Axial Fatigue (Transverse)[e]						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	79.0	(544.7)	NA		54.0	(372.3)
10^5 cycles, ksi (MPa)	64.9	(447.5)	NA		49.7	(342.7)
10^7 cycles, ksi (MPa)	59.0	(406.8)	NA		28.9	(199.3)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	61.0	(420.6)	NA		50.0	(344.8)
10^5 cycles, ksi (MPa)	23.5	(162.0)	NA		16.0	(110.3)
10^7 cycles, ksi (MPa)	20.0	(137.9)	NA		10.0	(69.0)
Stress Corrosion[d]						
K_{ISCC} = 3 ksi$\sqrt{in.}$ (3.3 MPa·m$^{1/2}$)						
Density						
ω = 0.102 lb/in.^{3} (2.823 g/cc)						

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) K_{IC} is valid as per ASTM E399.

(c) NA, not applicable.

(d) This value is an approximate determination of K_{ISCC} at 10^{-8} in./sec. (25.4 x 10^{-8} mm/sec.). This value appears low due to scatter. The increasing K tests lasted an average of 3 days and were conducted at 75 F (297 K) in 3½% NaCl. Compact-tension-type specimens were used.

(e) The unnotched fatigue tests were conducted using a test section diameter of 0.18 inch (4.57 mm). ASTM E466 suggests a test section diameter between 0.200 inch (5.08 mm) and 1.000 inch (25.4 mm), however it is felt these are valid test results.

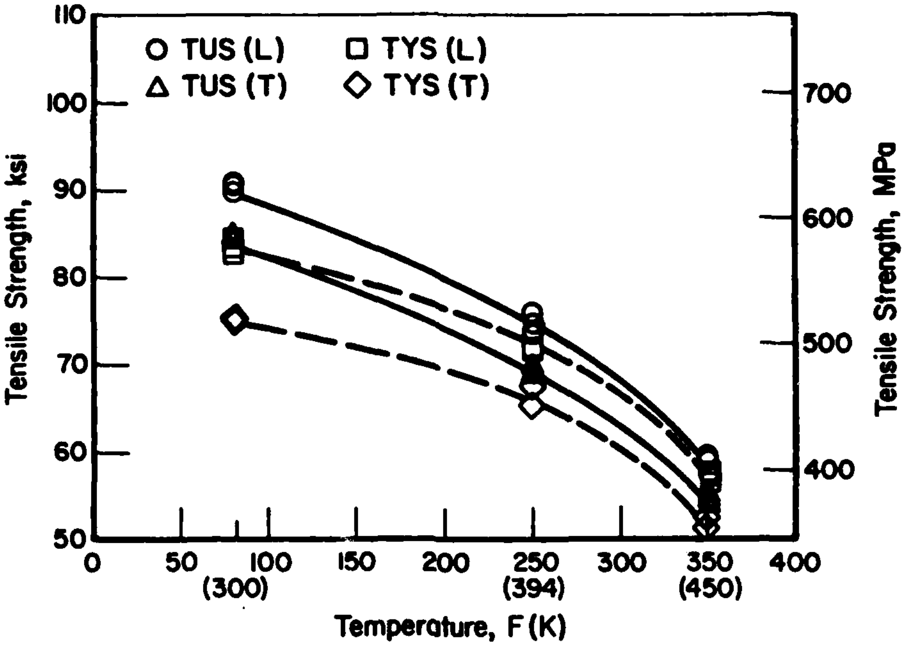


Figure 1. Effect of temperature on the tensile strength of CT 91-T7E69 aluminum.

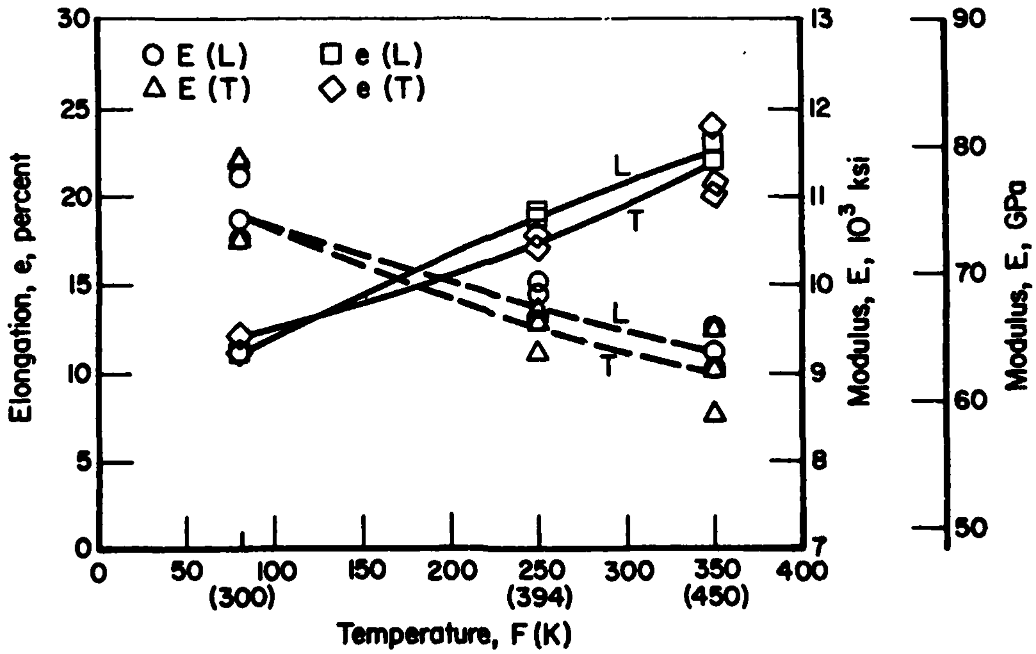


Figure 2. Effect of temperature on tensile properties of CT 91-T7E69 aluminum.

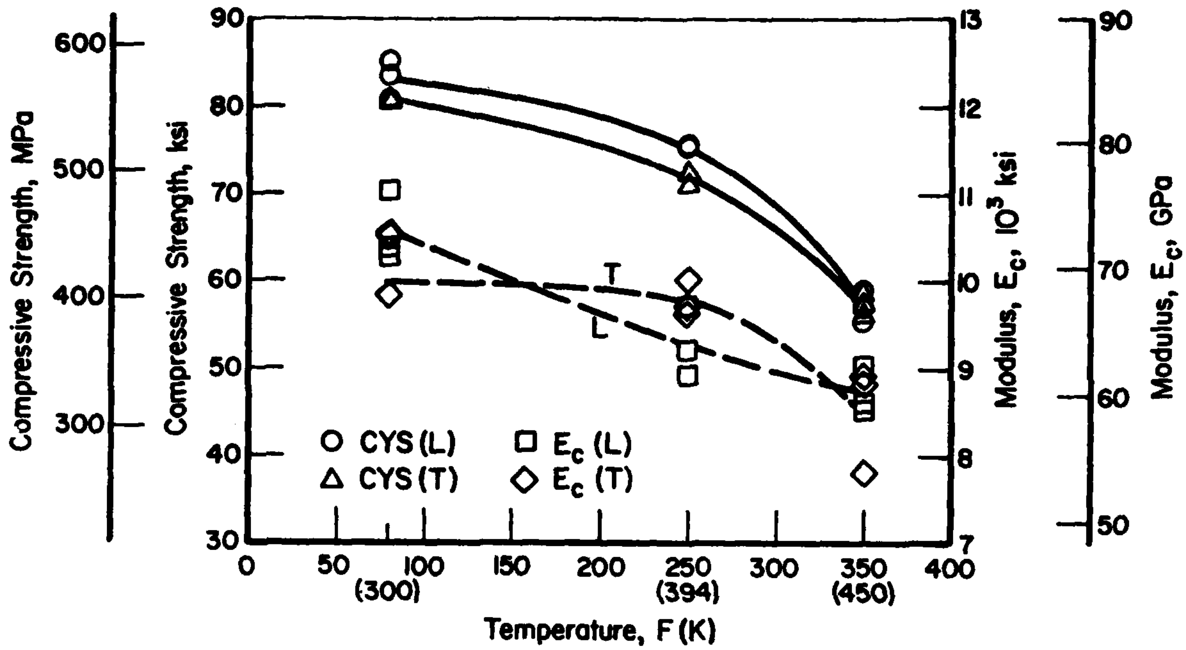


Figure 3. Effect of temperature on the compressive properties of CT 91-T7E69 aluminum.

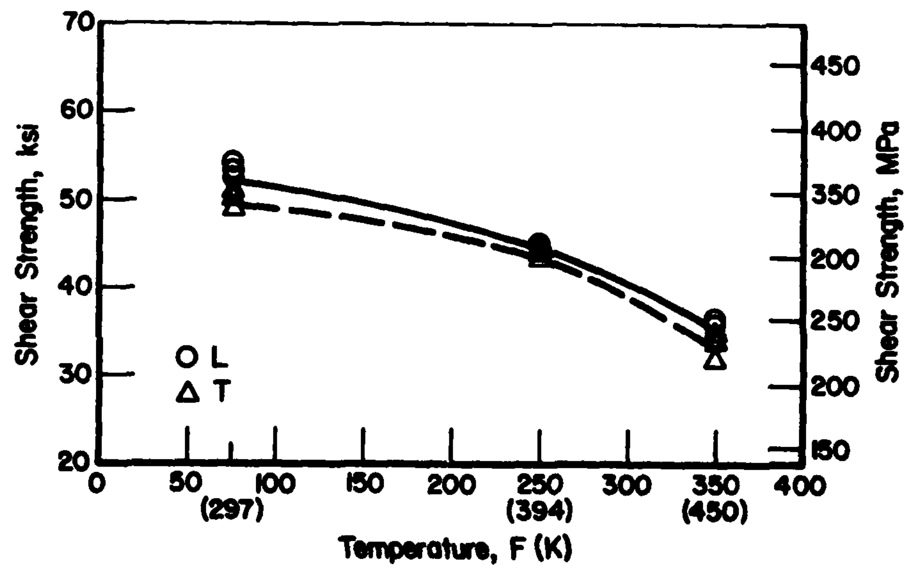


Figure 4. Effect of temperature on pin shear properties of CT 91-T7E69 aluminum.

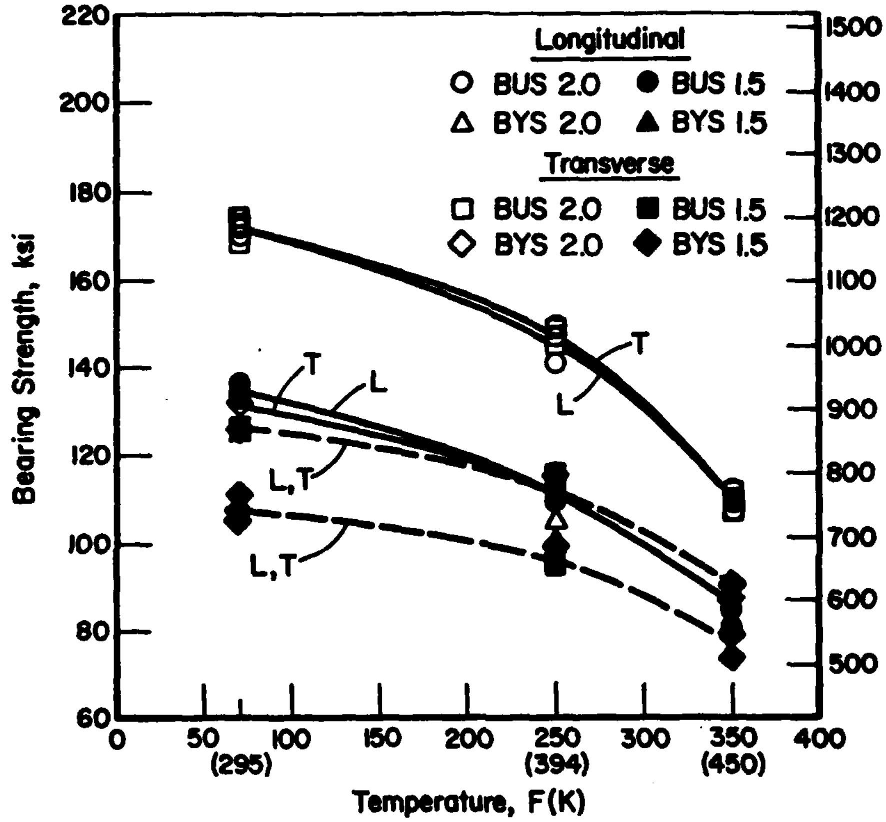


Figure 5. Effect of temperature on the bearing properties of CT 91-T7E69 aluminum.

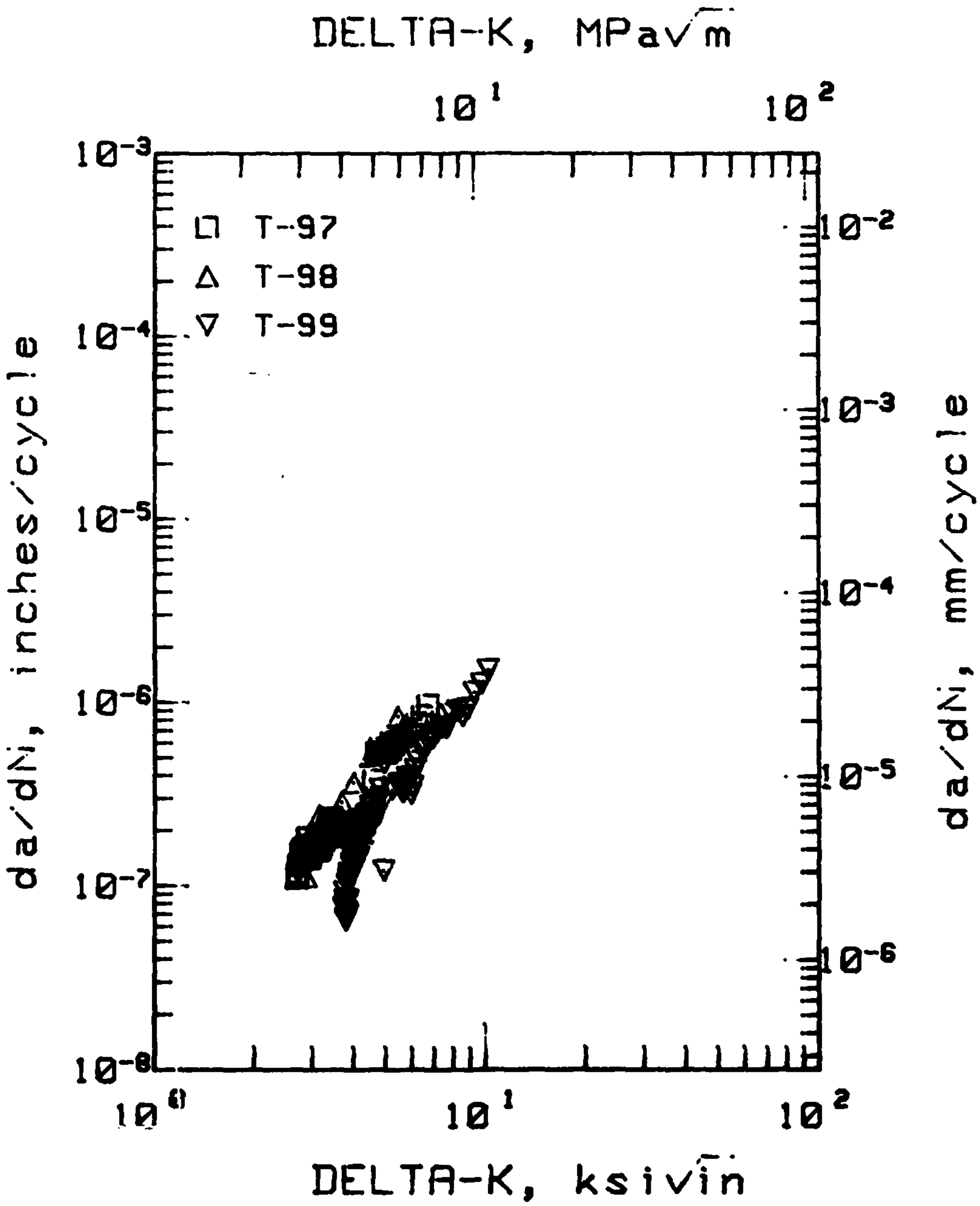


Figure 6. da/dN versus delta K for CT 91-T7E69 aluminum.

Lab Air
R = 0.1
Frequency = 20 Hz

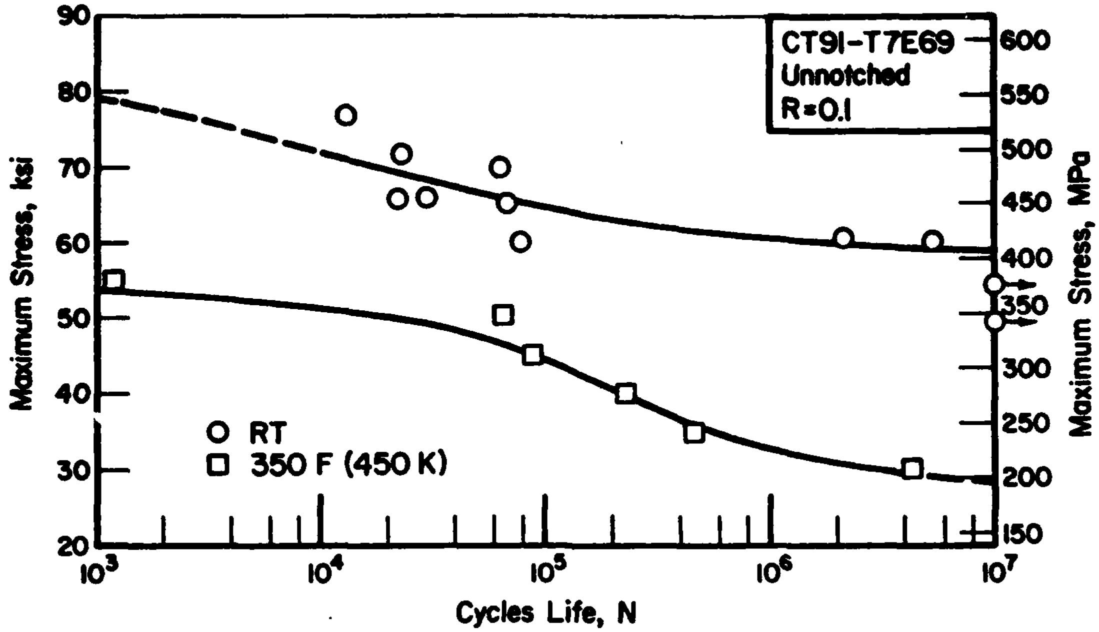


Figure 7. Axial load fatigue behavior of unnotched CT 91-T7E69 aluminum.

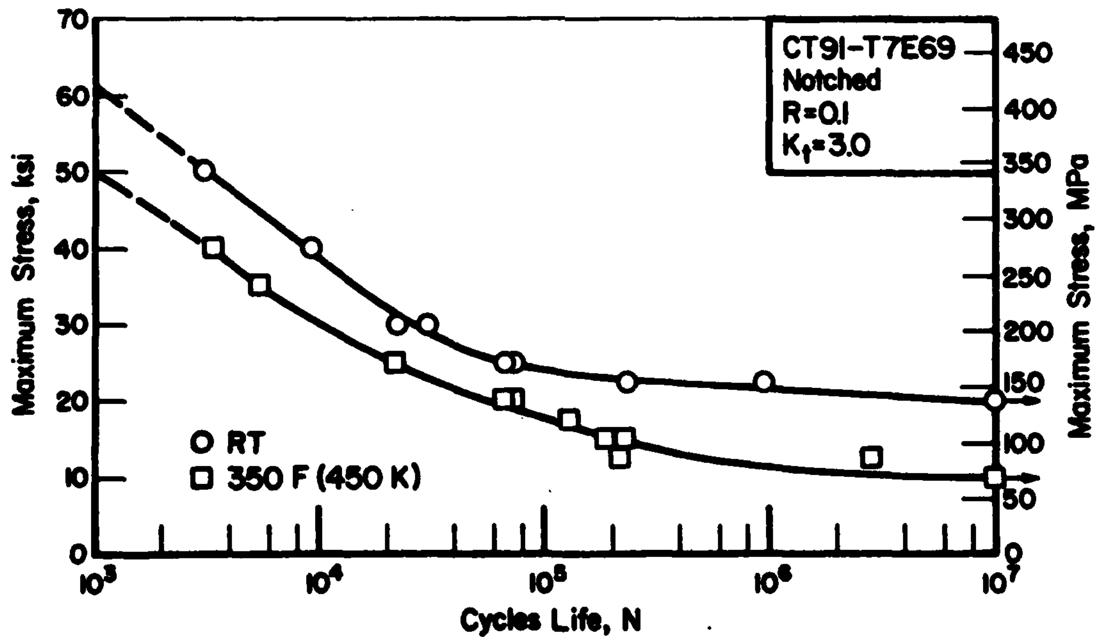


Figure 8. Axial load fatigue behavior of notched (K_t = 3.0) CT 91-T7E69 aluminum.

MECHANICAL-PROPERTY DATA
Ti-10V-2Fe-3Al ALLOY

ISOTHERMALLY FORGED

Issued by

Air Force Wright Aeronautical Laboratory
Materials Laboratory
Wright-Patterson Air Force Base, Ohio

June 1982

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-80-C-5168

Ti-10V-2Fe-3Al Isothermally Forged

Material Description

Ti-10V-2Fe-3Al is a recently developed, metallurgically near-beta alloy. The alloy is capable of attaining a variety of strength levels, depending on the selection of heat treatment. A major advantage over other alloys is the excellent forgeability. It forms readily at temperatures below those required for Ti-6Al-4V.

The Ti-10V-2Fe-3Al material used in this evaluation was received as 6 discs 7 inches (178 mm) in diameter x 1/2-inch (12.7 mm) thick. The material was produced by RMI and isothermally forged by TRW.

The chemical composition of this lot is as follows:

Chemical Composition	Percent Weight
Vanadium	9.5
Aluminum	3.2
Iron	1.9
Titanium	Balance

Processing and Heat Treating

A 30-inch (762 mm) diameter cast ingot was first heated to 2200 F (1478 K) and forged to a 24-inch (610 mm) round cornered square (RCS). The billet was then heated to 1400 F (1033 K) and forged to a 20-inch (508 mm) RCS, reheated to 1700 F (1200 K) and forged to a 15-inch (381 mm) RCS, reheated to 1700 F (1200 K) and once more forged to an 11-inch (279 mm) RCS bar. Conditioning of the piece was conducted as needed during the processing. A section of the material was then cut, heated to 1375 F (1019 K) and forged into an 8-inch (203 mm) RCS, reheated to 1700 F (1200 K) and forged to a 5-inch (127 mm) RCS, reheated to 1500 F (1089 K) and forged to a 4-inch (102 mm) octagon. A final pass at RMI was performed in a rotary forging machine at 1500 F (1089 K) transforming the octagon into a 3-1/4-inch (82.6 mm) diameter round bar.

At TRW the round bar was conventionally upset 25% at 1525 F (1103 K), conventionally drawn 40% at 1525 F (1103 K), isothermally drawn 50% at 1525 F (1103 K), and isothermally forged 50% to the final shape. The material was subsequently heat treated as follows: 1435 F (1052 K)/ 2 hours/air cool, 1425 F (1047 K)/2 hours/water quench, and 945 F (780 K)/ 8 hours/air cool (STA).

Ti-10V-2Fe-3Al[a]

Condition: STA
Thickness: 1/2-inch (12.7 mm)

Properties	Temperature, F (K)			
	RT	(RT)	600	(587)
Tension				
TUS, L, ksi (MPa)	179.2	(1235.6)	153.2	(1056.3)
TUS, T, ksi (MPa)	178.8	(1232.8)	154.9	(1068.0)
TYS, L, ksi (MPa)	173.9	(1199.0)	136.6	(941.9)
TYS, T, ksi (MPa)	173.7	(1197.7)	141.2	(973.6)
e, L, percent in 2 in. (50.8 mm)	2.3		8.3[b]	
e, T, percent in 2 in. (50.8 mm)	2.0		6.5[b]	
E, L, 10^3 ksi (GPa)[d]	15.46	(106.6)	13.98	(96.4)
E, T, 10^3 ksi (GPa)[d]	15.12	(104.2)	13.98	(96.4)
Compression				
CUS, L, ksi (MPa)[b,c]	213.7	(1473.5)		
CUS, T, ksi (MPa)	211.4	(1457.6)		
CYS, T, ksi (MPa)	191.8	(1322.5)		
E_c, L, 10^3 ksi (GPa)[b,d]	16.60	(114.4)		
E_c, T, 10^3 ksi (GPa)[d]	16.09	(110.9)		
Shear				
SUS, L, ksi (MPa)	98.6	(679.8)		
SUS, T, ksi (MPa)	101.5	(699.8)		
Bearing				
e/D = 1.5				
BUS, L, ksi (MPa)	247.1	(1703.8)		
BUS, T, ksi (MPa)	264.8	(1825.8)		
BYS, L, ksi (MPa)	243.0	(1675.5)		
BYS, T, ksi (MPa)	258.9	(1785.1)		
e/D = 2.0				
BUS, L, ksi (MPa)	321.2	(2214.7)		
BUS, T, ksi (MPa)	309.5	(2134.0)		
BYS, L, ksi (MPa)	289.9	(1998.9)		
BYS, T, ksi (MPa)	280.8	(1936.1)		
Axial Fatigue (Transverse)				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	170	(1172)		
10^5 cycles, ksi (MPa)	120	(827)		
10^7 cycles, ksi (MPa)	110	(758)		
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	105	(724)		
10^5 cycles, ksi (MPa)	45	(310)		
10^7 cycles, ksi (MPa)	40	(276)		

(a) Values are average of triplicate tests conducted at Wright Aeronautical Laboratories, Materials Laboratory, unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) Data from only two tests.

(c) Ultimate strength value only due to test problems.

(d) The values presented are indicative of modulus values typical for titanium alloy materials; however, the instrumentation did not meet ASTM E83 class A extensometer requirements.

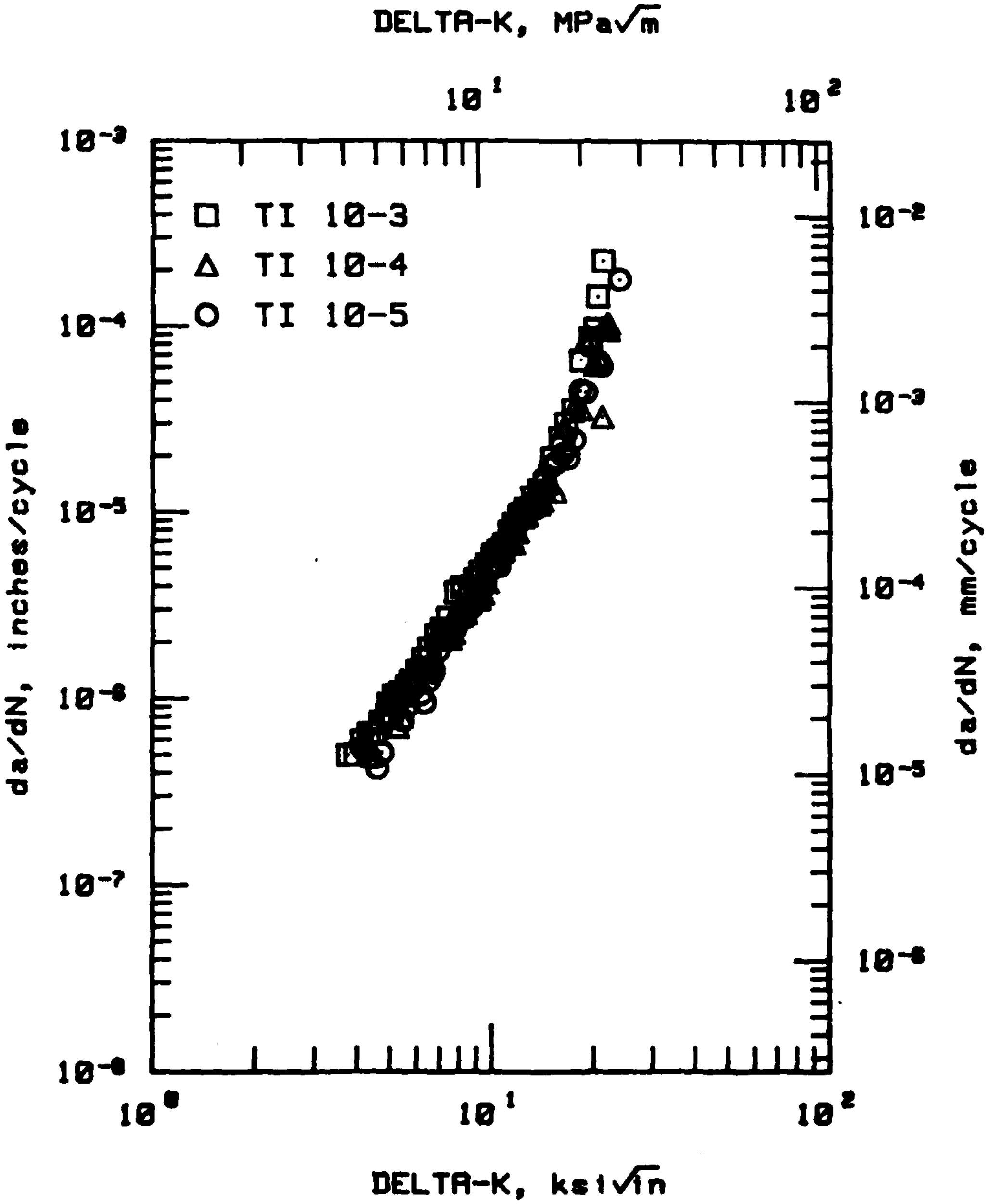


FIGURE 1. da/dN VERSUS DELTA K FOR Ti-10V-2Fe-3Al ALLOY.

Lab Air
Room Temperature
R = 0.1
Frequency = 30 Hz
Specimen Orientation = L-T

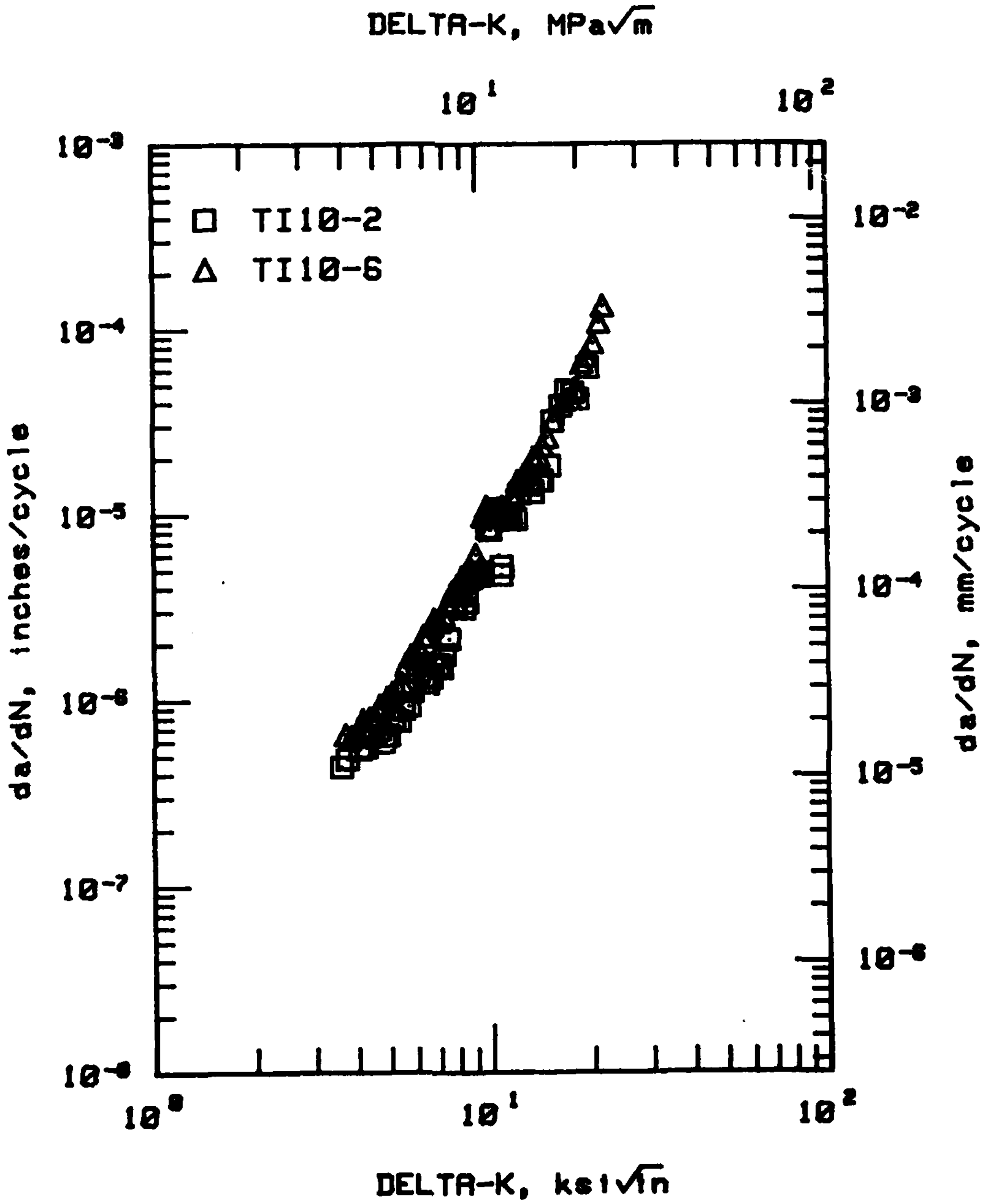


FIGURE 2. da/dN VERSUS DELTA K FOR Ti-10V-2Fe-3Al ALLOY.

Lab Air (Heated)
600 F (589 K)
R = 0.1
Frequency = 30 Hz
Specimen Orientation = L-T

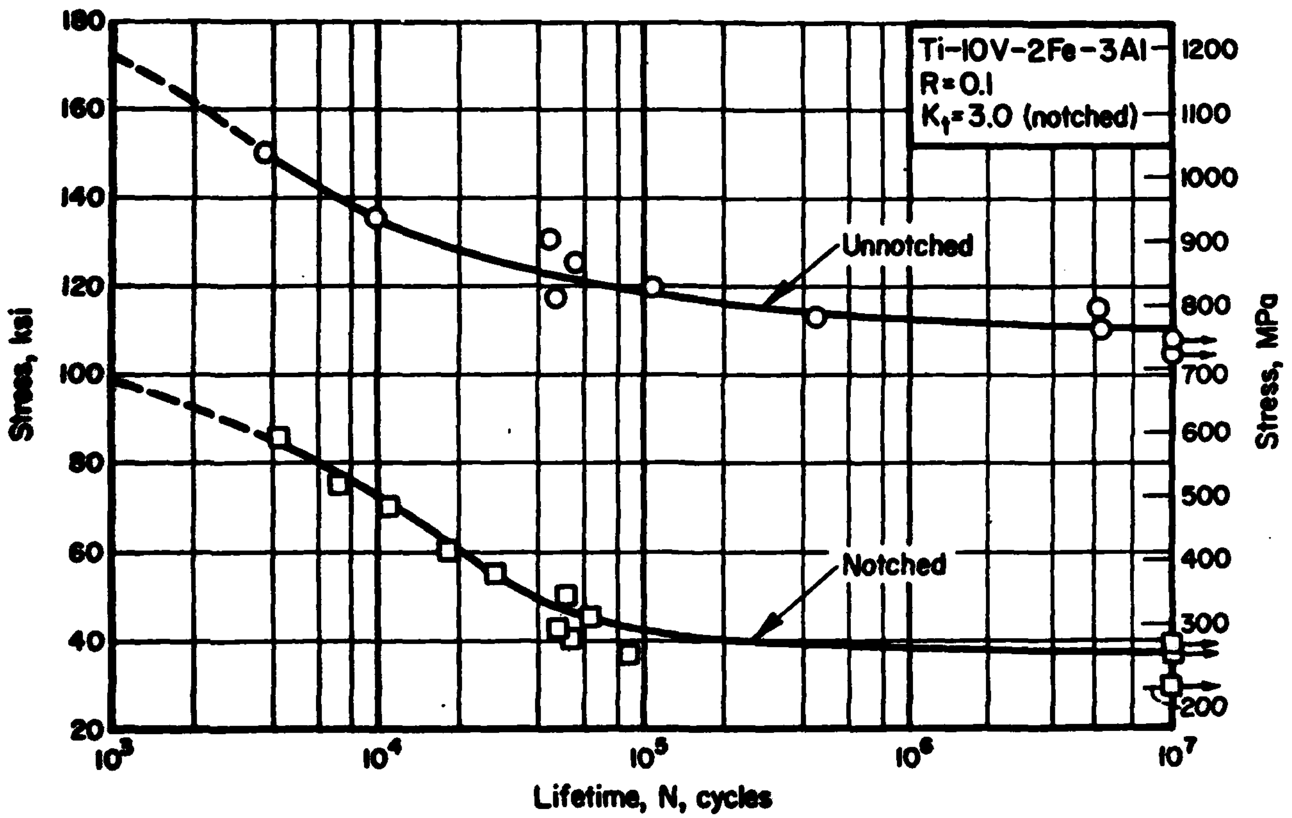
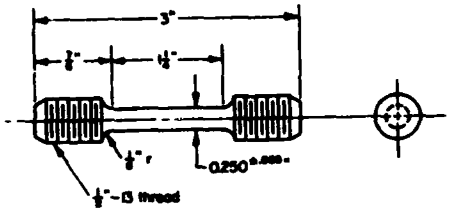


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED AND NOTCHED (K_t = 3.0) Ti-10V-2Fe-3Al ALLOY AT ROOM TEMPERATURE

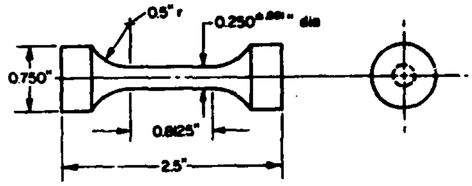
APPENDIX B

SPECIMEN DRAWINGS

1. Ti-6Al-4V (CHIP) alloy
2. CT-91-T7E69 aluminum
3. Ti-10V-2Fe-3Al pancake

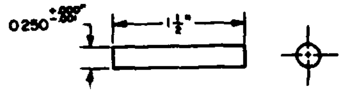


Tensile

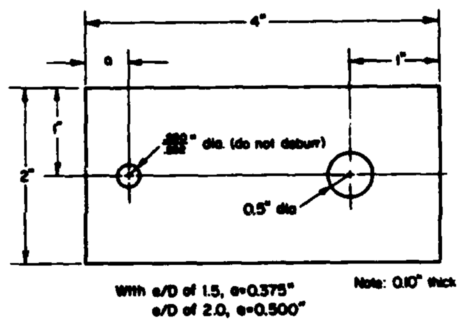


Note: Grind or machine ends of specimen so that ends of specimen shall be plane and perpendicular to the axis of the specimen within 0.25 degree. The ends shall be parallel within 0.0005".

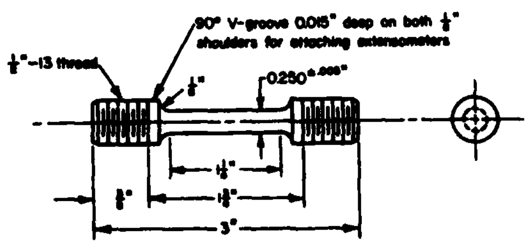
Compression



Shear pin

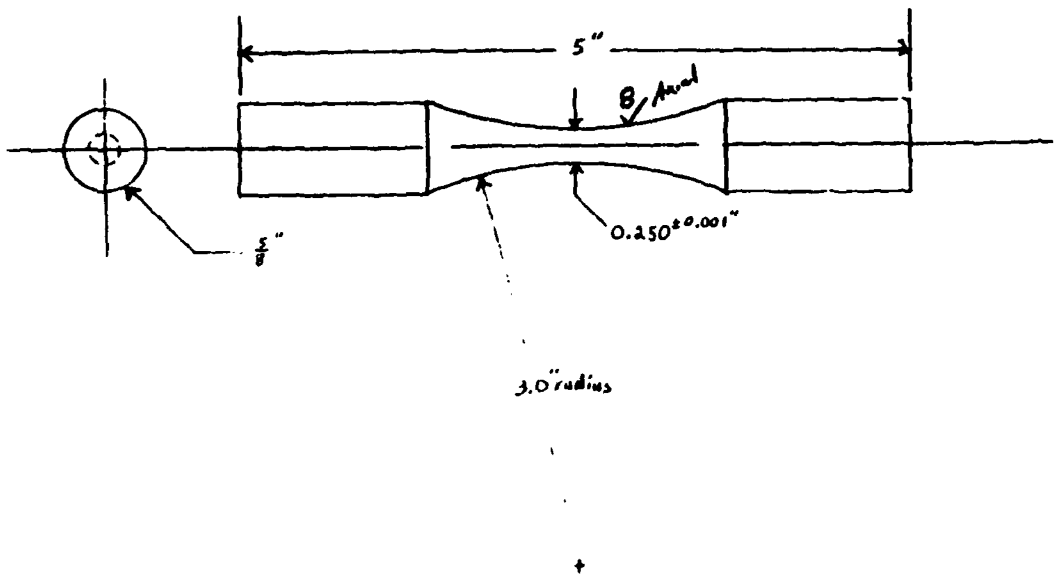


Bearing

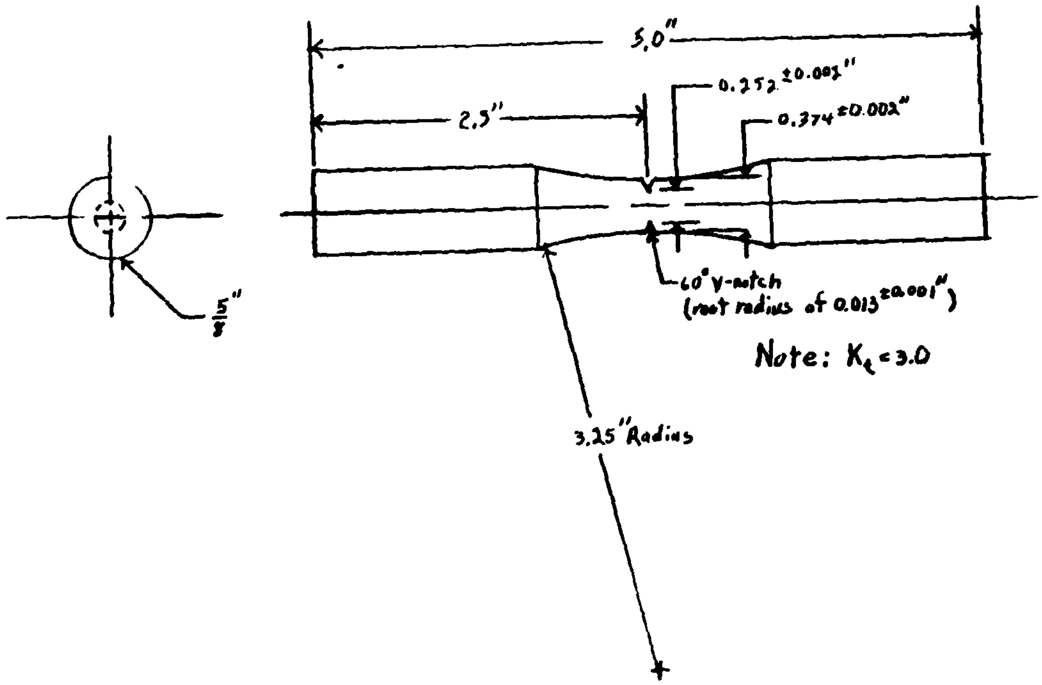


Creep

<u>ANNEALED Ti-6Al-4V (CHIP) ALLOY SPECIMENS</u>

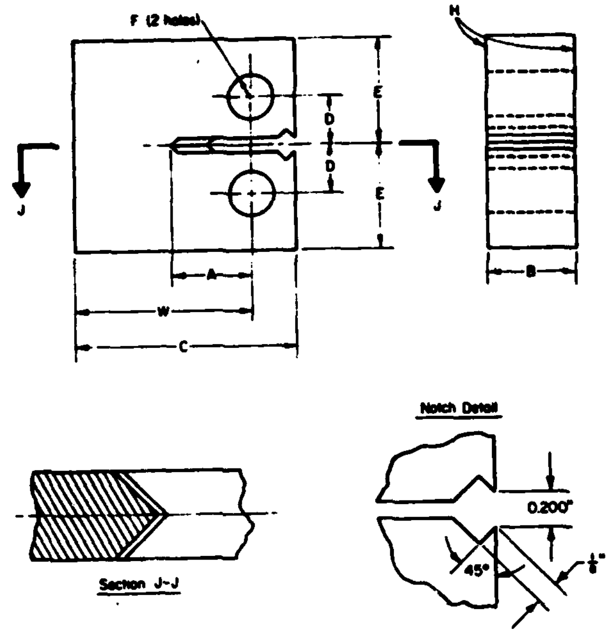


Unnotched fatigue



Notched fatigue

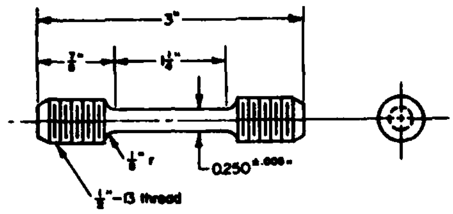
<u>ANNEALED Ti-6Al-4V (CHIP) ALLOY SPECIMENS</u> (Continued)



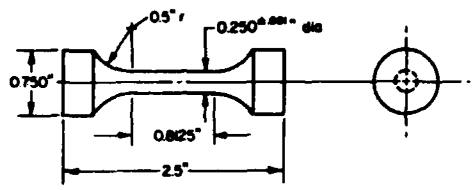
Crack Propagation

A 0.575
B 0.750
C 1.875
D 0.4125
E 0.900
F 0.378
W 1.500
H parallel within 0.002 W

<u>ANNEALED Ti-6Al-4V (CHIP) ALLOY SPECIMENS</u> (Concluded)

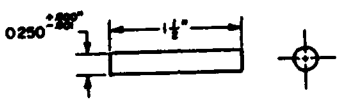


Tensile

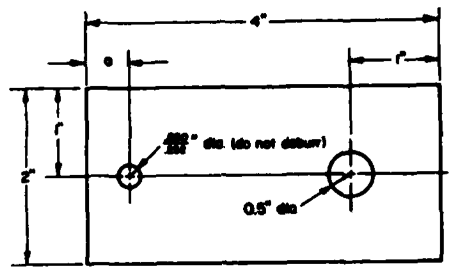


Note: Grind or machine ends of specimen so that ends of specimen shall be plane and perpendicular to the axis of the specimen within 0.25 degree. The ends shall be parallel within 0.0005".

Compression



Shear pin

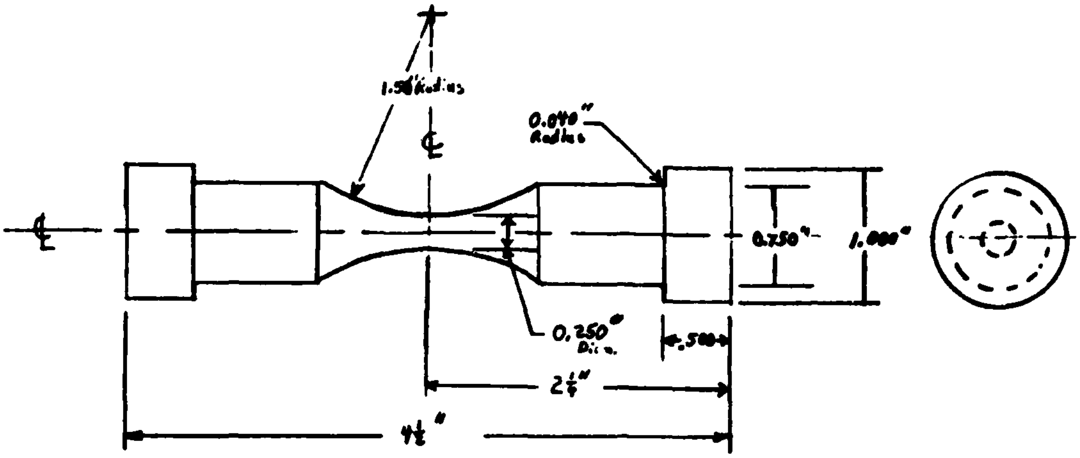


With e/D of 1.5, e=0.375"
e/D of 2.0, e=0.500"

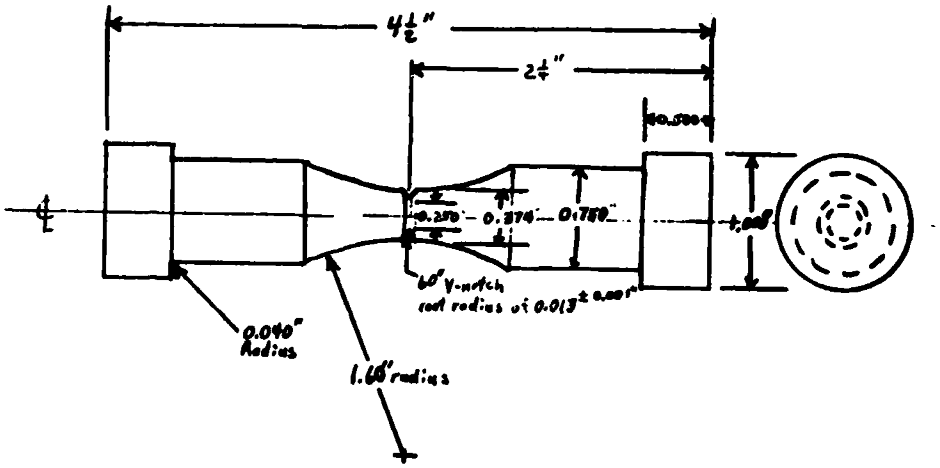
Note: 0.10" thick

Bearing

CT-91-T7E69 ALUMINUM EXTRUSION SPECIMENS

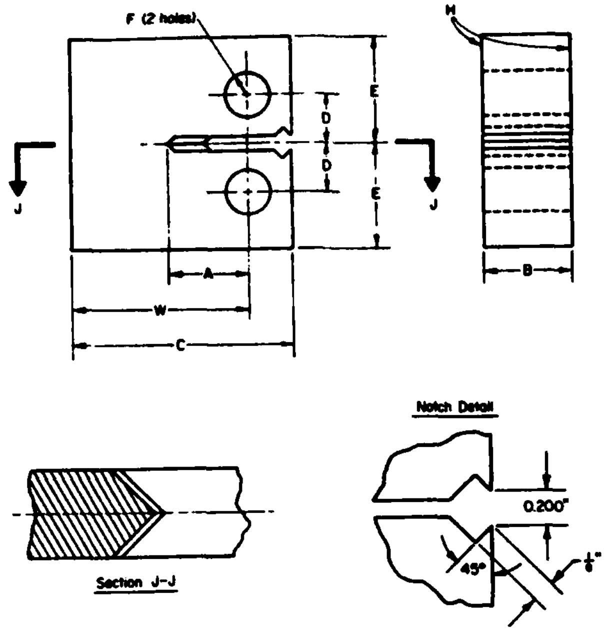


Unnotched fatigue



Notched Fatigue

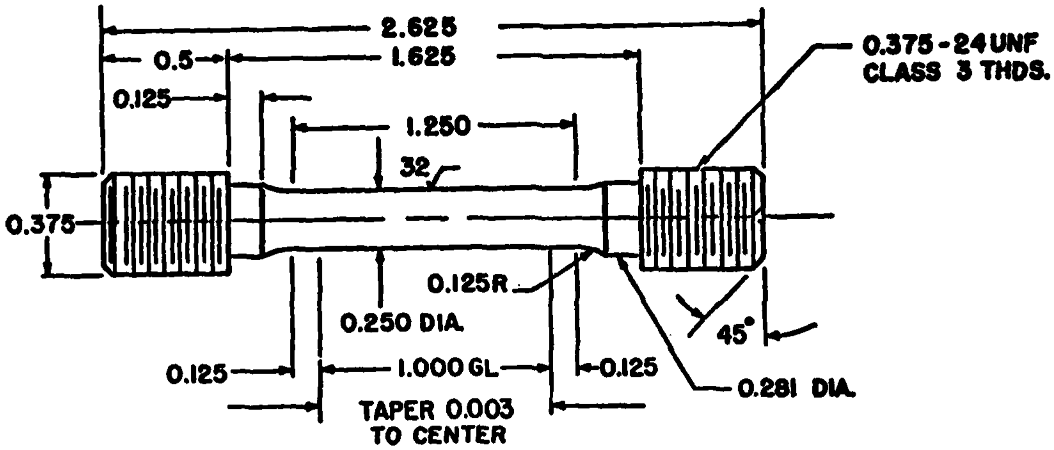
<u>CT-91-T7E69 ALUMINUM EXTRUSION SPECIMENS</u> **(Continued)**



Fracture toughness
Crack Propagation
Stress Corrosion

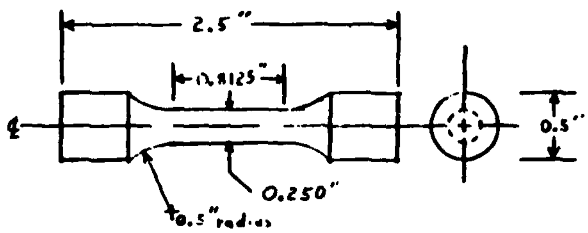
A 1.400
B 1.500
C 3.750
D 0.825
E 1.800
F 0.750
W 3.000
H parallel within 0.002 W

<u>CT-91-T7E69 ALUMINUM EXTRUSION SPECIMENS</u> (Concluded)



1. Threads to be concentric with central axis to 0.001
2. Gage length must not be undercut at ends.
3. Gage length must be free of circumfrential scratches.

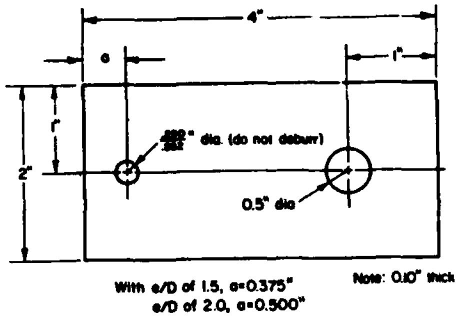
Tensile



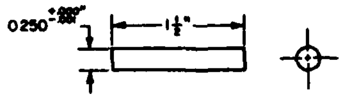
Note: Ends to be flat and parallel to within 0.0002" of ℄.

Compression

Ti-10V-2Fe-3Al ALLOY SPECIMENS

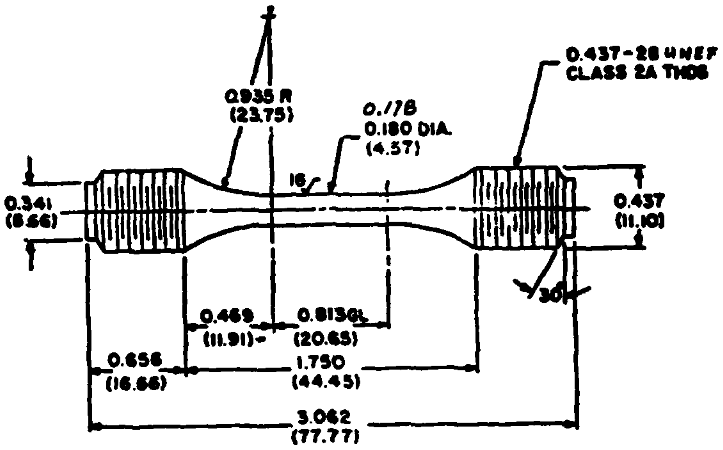


Bearing

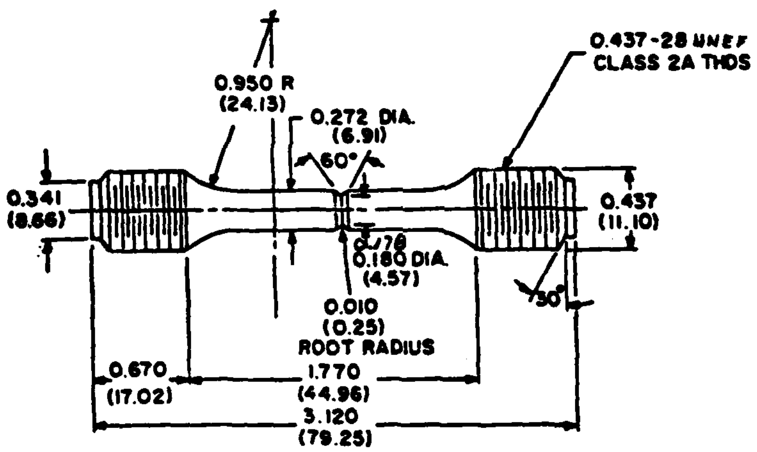


Shear pin

<u>Ti-10V-2Fe-3Al ALLOY SPECIMENS</u> (Continued)



Smooth Fatigue Specimen Configuration



DIMENSIONS IN INCHES
(mm)

Notched Fatigue Specimen Configuration

1. Taper gage length (G.L.) .001 from ends to center.
2. Gage length must not be undercut at ends.
3. Polish longitudinally--G.L. must be free from circumfrential scratches
4. Center drilling is permitted.

Ti-10V-2Fe-3Al ALLOY SPECIMENS (Concluded)

APPENDIX C

AF 1410 SUPPLEMENTAL DATA

1. AF 1410 Steel Plate
2. AF 1410 Steel Die Forgings

TABLE OF CONTENTS (APPENDIX C)

	Page
AF 1410 Steel Plate	114
AF 1410 Steel Die Forging	135

LIST OF ILLUSTRATIONS

		Page
Figure C-1.	Specimen layout for AF 1410 Plate	115
C-2.	Typical Tensile Longitudinal Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	125
C-3.	Typical Tensile Transverse Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	126
C-4.	Typical Compressive Longitudinal Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	127
C-5.	Typical Compressive Longitudinal Tangent Modulus Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	128
C-6.	Typical Compressive Transverse Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	129
C-7.	Typical Compressive Transverse Tangent-Modulus Curves at Temperature for Double Austenitized and Aged AF 1410 Steel Plate	130
C-8.	Effect of Temperature on the Tensile Properties of Double Austenitized and Aged AF 1410 Steel Plate	131
C-9.	Effect of Temperature on the Compressive Properties of Double Austenitized and Aged AF 1410 Steel Plate	131
C-10.	Effect of Temperature on the Shear Properties of Double Austenitized and Aged AF 1410 Steel Plate	132
C-11.	Effect of Temperature on the Compressive Properties of Double Austenitized and Aged AF 1410 Steel Plate	132
C-12.	Axial Load Fatigue Behavior of Unnotched Double Austenitized and Aged AF 1410 Steel Plate	133
C-13.	Axial Load Fatigue Behavior of Notched (K_t= 3.0) Double Austenitized and Aged AF 1410 Steel Plate	133
C-14.	Creep Rupture and Plastic Deformation Curves for Transverse AF 1410 Steel Plate	134
C-15.	AF 1410 Steel Die Forgings	136
C-16.	Typical Tensile Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Die Forgings	142
C-17.	Typical Compressive Stress-Strain Curves at Temperature for Double Austenitized and Aged AF 1410 Die Forgings	143

LIST OF ILLUSTRATIONS (Continued)

		Page
C-18.	Typical Compressive Tangent-Modulus Curves for Double Austenitized and Aged AF 1410 Die Forgings . . .	144
C-19.	Effect of Temperature on the Tensile Properties of AF 1410 Die Forgings	145
C-20.	Effect of Temperature on the Compressive Properties of AF 1410 Die Forgings	145
C-21.	Effect of Temperature on the Shear Properties of AF 1410 Die Forgings	146
C-22.	Axial Load Fatigue Behavior of Unnotched and Notched AF 1410 Die Forgings at Room Temperature	146

LIST OF TABLES

		Page
Table C-1.	Results of Tensile Tests on Double Austenitized and Aged AF 1410 Steel Plate	117
C-2.	Results of Compression Tests on Double Austenitized and Aged AF 1410 Steel Plate	118
C-3.	Results of Pin Shear Tests for AF 1410 Steel Plate . .	119
C-4.	Results of Bearing Tests at e/D = 1.5 and e/D = 2.0 for AF 1410 Steel Plate at Room Temperature	120
C-5.	Results of Charpy Impact Tests for AF 1410 Steel Plate	121
C-6.	Results of Compact Tension Fracture Toughness Tests for AF 1410 Steel Plate	121
C-7.	Results of Axial Load Fatigue Tests for Unnotched AF 1410 Steel at a Stress Ratio of R = 0.1	122
C-8.	Results of Axial Load Fatigue Tests for Notched (K_t = 3.0) AF 1410 Steel at a Stress Ratio of R = 0.1 .	123
C-9.	Summary Data on Creep and Rupture Properties for Double Austenitized and Aged AF 1410 Steel Plate (Transverse)	124
C-10.	Results of Longitudinal Tensile Tests for AF 1410 Steel Die Forgings	138
C-11.	Results of Longitudinal Compression Tests for AF 1410 Steel Die Forgings	139
C-12.	Results of Longitudinal Pin Shear Tests on AF 1410 Steel Die Forgings	140
C-13.	Results of Longitudinal Charpy Impact Tests at Room Temperature on AF 1410 Steel Die Forgings	140
C-14.	Results of Axial Load Fatigue Tests at Room Temperature for Unnotched and Notched (K_t = 3.0) AF 1410 Steel Die Forgings at a Stress Ratio of R = 0.1	141

AF 1410 Steel Plate

Material Description

This material is the result of a cooperative development program by General Dynamics and U.S. Steel under the sponsorship of the Air Force Materials Laboratory. The development requirement was for a weldable high-strength steel alloy, possessing a combined high fracture toughness and stress-corrosion resistance.

Considerable information and additional data for AF 1410 is contained in the final report on Contract F33615-73C-5093, AFML-TR-75-148, "Development of a Weldable High-Strength Steel", September, 1975.

The material used in this evaluation was plate from Heat 9 which is described in the above report.

Processing and Heat Treating

The plate was received in a double-austenitized condition. Specimens were aged at 950°F (783 K) for 5 hours and air cooled. The specimen layout is shown in Figure C-1.

Test Results

Tension. Results of tests on longitudinal and transverse specimens at room temperature, 400°F (477 K), and 800°F (700 K) are given in Table C-1. Typical tensile stress-strain curves at temperature are shown in Figures C-2 and C-3. Effect-of-temperature curves are presented in Figure C-8.

Compression. Results of longitudinal and transverse tests at room temperature, 400°F (477 K), and 800°F (700 K) are shown in Table C-2. Typical stress-strain and tangent-modulus curves are presented in Figures C-4 through C-7. Effect-of-temperature curves are shown in Figure C-9.

Shear. Results of double-shear pin type tests on longitudinal and transverse specimens at room temperature, 400°F (477 K), and 800°F (700 K) are given in Table C-3. Effect-of-temperature curves are presented in Figure C-10.

Bearing. Tests were conducted at both $e/D = 1.5$ and $e/D = 2.0$ for longitudinal and transverse specimens at room temperature, 400°F (477 K), and 800°F (700 K). Results are given in Table C-4. Effect-of-temperature curves are presented in Figure C-11.

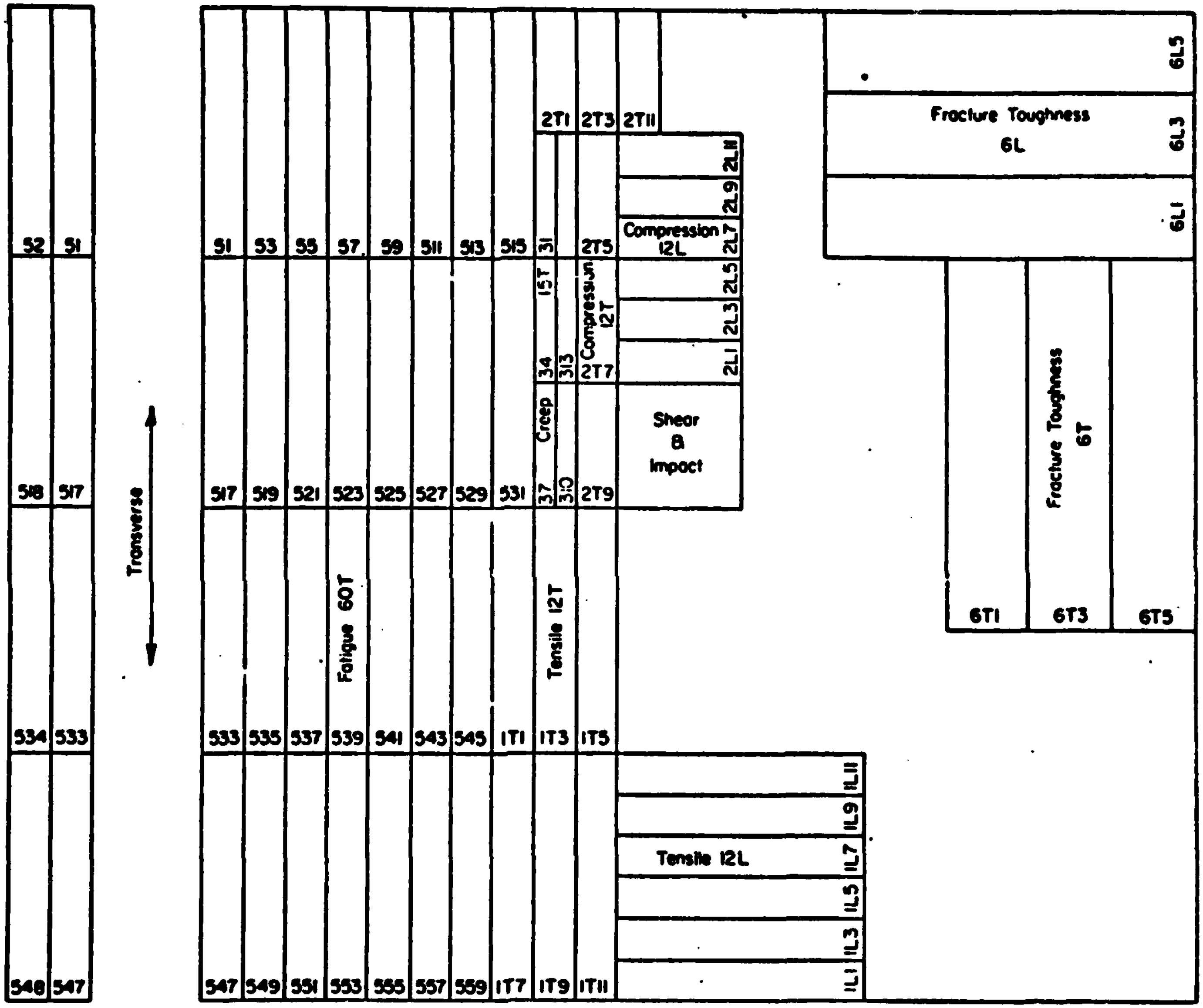


FIGURE C-1. SPECIMEN LAYOUT FOR AF 1410 PLATE

Impact. Results of Charpy tests for longitudinal and transverse specimens at room temperature are given in Table C-5.

Fracture Toughness. Results of compact tension type tests for longitudinal and transverse specimens at room temperature are given in Table C-6. The K_Q values shown are considered valid K_{Ic} values per ASTM E399.

Fatigue. Results of axial load tests at room temperature, 400°F (477 K), and 800°F (700 K) unnotched and notched transverse specimens are shown in Tables C-7 and C-8. S-N curves are presented in Figures C-12 and C-13.

Creep and Stress Rupture. Tests were conducted at 600°F (588 K), and 800°F (700 K) for transverse specimens. Test results are given in Table C-9. Log-stress versus log-time curves are presented in Figure C-14.

Stress Corrosion. K_{Iscc} test attempts did not yield any usable data. The value of K_{Iscc} reported in AFML-TR-75-148 is 95 ksi$\sqrt{in}$ (104 MPa$\sqrt{m}$).

Thermal Expansion. The coefficient of thermal expansion for this material is 6.1×10^{-6} in/in/F (70 - 800°F) (1.10×10^{-5} m/m/k (294 - 700 K)).

Density. The density of this alloy is 0.285 lb/in^3 (7.89 Mg/m^3).

TABLE C-1. RESULTS OF TENSILE TESTS ON DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE.

Specimen Number	Tensile Ultimate Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 1 Inch, (25.4 mm) percent	Reduction in area, percent	Tensile Modulus, 10^3 ksi	(GPa)
Longitudinal at Room Temperature (RT)								
1L-1	236.2	(1628.6)	232.6	(1603.8)	15.0	69.9	26.5	(182.7)
1L-2	238.6	(1645.2)	233.0	(1606.5)	14.7	61.7	27.8	(191.7)
1L-3	235.0	(1620.3)	231.9	(1598.9)	16.0	67.5	27.0	(186.2)
Average	236.6	(1631.4)	232.5	(1603.1)	15.2	63.4	27.1	(186.8)
Transverse at Room Temperature (RT)								
1T-1	240.8	(1660.3)	235.0	(1620.3)	16.7	65.1	28.0	(193.1)
1T-2	242.0	(1668.6)	230.6	(1590.0)	14.0	69.0	27.7	(191.0)
1T-3	237.6	(1638.3)	232.6	(1603.8)	15.0	61.1	26.9	(185.5)
Average	240.1	(1655.5)	232.7	(1604.5)	15.2	65.1	27.5	(189.6)
Longitudinal at 400°F (477 K)								
1L-4	214.1	(1476.2)	210.7	(1452.8)	14.0	67.4	30.5	(210.3)
1L-5	213.6	(1472.8)	213.6	(1472.8)	15.0	68.2	28.5	(196.5)
1L-6	213.6	(1472.8)	209.2	(1442.4)	15.0	70.0	28.1	(193.8)
Average	213.8	(1474.2)	211.2	(1456.2)	14.7	68.5	29.0	(200.0)
Transverse at 400°F (477 K)								
1T-4	216.8	(1494.8)	213.1	(1469.3)	15.0	68.3	29.4	(202.7)
1T-5	216.6	(1493.5)	209.6	(1445.2)	15.0	66.1	29.2	(201.3)
1T-6	216.4	(1492.1)	208.1	(1434.9)	15.0	67.6	28.6	(197.2)
Average	216.6	(1493.5)	210.3	(1450.0)	15.0	67.3	29.1	(200.6)
Longitudinal at 800°F (700 K)								
1L-7	186.1	(1283.2)	176.8	(1219.0)	16.0	67.4	22.6	(155.8)
1L-8	186.5	(1285.9)	172.9	(1192.2)	15.0	68.3	22.6	(155.8)
1L-9	186.9	(1288.7)	174.7	(1204.6)	16.0	70.1	24.2	(166.9)
Average	186.5	(1285.9)	174.8	(1205.3)	15.7	68.6	23.1	(159.3)
Transverse at 800°F (700 K)								
1T-7	188.2	(1297.7)	175.0	(1206.6)	16.0	68.2	24.2	(166.9)
1T-8	186.5	(1285.9)	169.8	(1170.8)	16.0	66.1	26.0	(179.3)
1T-9	188.1	(1296.9)	173.2	(1194.2)	16.0	67.6	24.2	(166.9)
Average	187.6	(1293.5)	172.7	(1190.8)	16.0	67.3	24.8	(171.0)

TABLE C-2. RESULTS OF COMPRESSION TESTS ON DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

Specimen Number		0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(GPa)
		Longitudinal at Room Temperature (RT)			
2L-1		236.3	(1629.3)	28.9	(199.3)
2L-2		239.5	(1651.4)	29.7	(204.8)
2L-3		239.5	(1651.4)	29.1	(200.6)
	Average	238.4	(1643.8)	29.2	(201.3)
		Transverse at Room Temperature (RT)			
2T-1		237.4	(1636.8)	29.4	(202.7)
2T-2		232.8	(1605.2)	28.9	(199.3)
2T-3		229.2	(1580.3)	29.5	(203.4)
	Average	233.1	(1607.2)	29.3	(202.0)
		Longitudinal at 400°F (477 K)			
2L-4		211.9	(1461.1)	23.8	(164.1)
2L-5		210.2	(1449.3)	27.6	(190.3)
2L-6		211.7	(1459.7)	27.2	(187.5)
	Average	211.3	(1456.9)	26.2	(180.7)
		Transverse at 400°F (477K)			
2T-4		209.2	(1442.4)	25.4	(175.1)
2T-5		209.1	(1441.7)	25.8	(177.9)
2T-6		208.1	(1434.9)	26.9	(185.5)
	Average	208.8	(1439.7)	26.0	(179.3)
		Longitudinal at 800°F (700K)			
2L-7		176.2	(1214.9)	21.1	(145.5)
2L-8		177.7	(1225.2)	20.7	(142.7)
2L-9		176.3	(1215.6)	25.0	(172.4)
	Average	176.7	(1218.4)	22.3	(153.8)
		Transverse at 800°F (700 K)			
2T-7		168.4	(1161.2)	23.0	(158.6)
2T-8		170.9	(1178.4)	21.3	(146.9)
2T-9		168.9	(1164.6)	21.2	(146.2)
	Average	169.4	(1168.0)	21.8	(150.3)

TABLE C-3. RESULTS OF PIN SHEAR TESTS FOR AF 1410 STEEL PLATE

Specimen Number		Shear Ultimate Strength, ksi (MPa)	
	Room Temperature (Longitudinal)		
4L-1		145.3	(1001.8)
4L-2		148.5	(1023.9)
4L-3		148.3	(1022.5)
	Average	147.4	(1016.3)
	Room Temperature (Transverse)		
4T-1		144.9	(999.1)
4T-2		144.7	(997.7)
4T-3		145.0	(999.8)
	Average	144.9	(999.1)
	400°F 477K (Longitudinal)		
4L-4		128.7	(887.4)
4L-5		127.8	(881.2)
4L-6		125.5	(865.3)
	Average	127.3	(877.7)
	400°F 477K (Transverse)		
4T-4		129.0	(889.5)
4T-5		128.3	(884.6)
4T-6		130.0	(896.4)
	Average	129.1	(890.1)
	800°F 700K (Longitudinal)		
4L-7		105.8	(729.5)
4L-8		106.4	(733.6)
4L-9		106.7	(735.7)
	Average	106.2	(732.2)
	800°F 700K (Transverse)		
4T-7		107.9	(743.9)
4T-8		107.9	(743.9)
4T-9		106.1	(731.6)
	Average	107.3	(739.8)

TABLE C-4. RESULTS OF BEARING TESTS AT e/D = 1.5 and e/D = 2.0 FOR AF 1410 STEEL PLATE AT ROOM TEMPERATURE

Specimen Number	Bearing Ultimate Strength, ksi (MPa)				Bearing Yield Strength, ksi (MPa)			
	e/D = 1.5		e/D = 2.0		e/D = 1.5		e/D = 2.0	
Longitudinal at Room Temperature (RT)								
L-7	444.0	(3061.4)	513.5	(3540.6)	356.0	(2454.6)	392.6	(2707.0)
L-8	376.0	(2592.5)	528.6	(3644.7)	352.0	(2427.0)	400.8	(2763.5)
L-9	365.0	(2516.7)	523.6	(3610.2)	322.0	(2220.2)	388.9	(2681.5)
Average	395.0	(2723.5)	521.9	(3598.5)	343.3	(2367.1)	394.1	(2717.3)
Transverse at Room Temperature (RT)								
T-20	357.1	(2462.2)	510.5	(3520.0)	311.5	(2147.8)	396.5	(2733.9)
T-21	414.0	(2854.5)	537.3	(3704.7)	356.0	(2454.6)	406.4	(2802.1)
T-22	400.0	(2758.0)	496.6	(3424.1)	341.5	(2354.6)	382.4	(2636.7)
Average	390.0	(2689.1)	514.8	(3549.6)	336.3	(2318.8)	395.1	(2724.2)
Longitudinal at 400°F (477 K)								
L-1	376.6	(2596.7)	469.9	(3240.0)	329.3	(2268.5)	356.9	(2460.8)
L-2	377.0	(2599.4)	479.6	(3306.8)	325.4	(2243.6)	364.6	(2513.9)
L-3	367.1	(2531.2)	496.6	(3424.1)	313.5	(2161.6)	369.6	(2548.4)
Average	373.6	(2575.9)	482.0	(3323.4)	322.7	(2225.0)	363.7	(2507.7)
Transverse at 400°F (477 K)								
T-23	361.9	(2495.3)	488.6	(3368.9)	313.5	(2161.6)	372.8	(2570.5)
T-24	377.0	(2599.4)	436.5	(3009.7)	325.4	(2243.6)	329.4	(2271.2)
T-25	372.5	(2568.4)	460.3	(3173.8)	325.5	(2244.3)	351.2	(2421.5)
Average	370.5	(2554.6)	461.8	(3184.1)	321.5	(2216.7)	351.1	(2420.8)
Longitudinal at 800°F (700 K)								
L-4	323.4	(2229.8)	408.4	(2815.9)	294.6	(1962.3)	337.0	(2323.6)
L-5	320.0	(2206.4)	418.6	(2886.3)	292.0	(2013.3)	341.3	(2353.3)
L-6	324.0	(2234.0)	412.7	(2845.6)	296.0	(2040.9)	329.4	(2271.2)
Average	322.5	(2223.6)	413.2	(2849.0	294.2	(2028.5)	335.9	(2316.0)
Transverse at 800°F (700 K)								
T-27	321.9	(2219.5)	408.4	(2815.9)	297.6	(2051.9)	337.0	(2323.6)
T-26	321.9	(2219.5)	400.8	(2763.5)	294.5	(2030.6)	325.4	(2243.6)
T-28	321.4	(2216.1)	408.4	(2815.9)	291.7	(2011.3)	337.0	(2323.6)
Average	321.7	(2218.1)	405.9	(2798.7)	294.6	(2031.3)	333.1	(2296.7)

TABLE C-5. RESULTS OF CHARPY IMPACT TESTS FOR AF 1410 STEEL PLATE

Specimen Number		Energy, ft/lbs (Joules)
	Longitudinal	
6L-1		41 (55.6)
6L-2		43 (58.3)
6L-3		42 (56.9)
	Average	41 (55.6)
	Transverse	
6T-1		39 (52.9)
6T-2		45 (61.0)
6T-3		42 (56.9)
	Average	42 (56.9)

TABLE C-6. RESULTS OF COMPACT TENSION FRACTURE TOUGHNESS TESTS FOR AF 1410 STEEL PLATE

Specimen Number	W, inches (mm) (50.8)	B, inches (mm) (25.4)	a, inches (mm)	P_Q, pounds (Newton)	P_{max}, pounds (Newton)	f(a/w)	K_Q ksi$\sqrt{in}$ (MPa$\sqrt{in}$)
				Longitudinal (L-T)			
6L-1	2.0	1.0	1.007 (25.42)	18,900 (84,071)	18,900 (84,071)	9.70	129.6 (142.4)
6L-2	2.0	1.0	1.05 (26.7)	17,600 (78,288)	17,600 (78,288)	10.37	129.1 (141.9)
6L-3	2.0	1.0	1.05 (26.7)	18,000 (80,068)	18,000 (80,068)	10.57	132.7 (145.8)
						Average	130.5 (143.4)
				Transverse (T-L)			
6T-1	2.0	1.0	1.037 (26.3)	18,000 (80,068)	18,000 (80,068)	10.12	128.8 (141.5)
6T-2	2.0	1.0	1.010 (25.6)	18,200 (80,957)	18,200 (80,957)	9.75	125.5 (137.9)
6T-3	2.0	1.0	1.007 (25.42)	18,500 (82,292)	18,500 (82,292)	9.70	126.9 (139.4)
						Average	127.1 (139.7)

TABLE C-7. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED AF1410 STEEL AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature (RT)		
5-8	245	(1689.3)	27,000
5-1	240	(1654.8)	36,000
5-6	235	(1620.3)	57,500
5-3	230	(1585.9)	184,100
5-5	225	(1551.4)	251,100
5-7	222.5	(1534.1)	3,325,500
5-2	220	(1516.9)	3,467,800
5-4	215	(1482.4)	5,987,200
5-10	210	(1447.9)	10,000,000[a]
5-1	200	(1379.0)	10,030,000[a]
	400°F (477 K)		
5-12	230	(1585.9)	10,000
5-11	225	(1551.4)	81,600
5-13	220	(1516.9)	303,400
5-14	215	(1482.4)	969,600
5-15	210	(1447.9)	1,476,200
5-16	205	(1413.5)	1,826,300
5-17	200	(1379.0)	9,770,400
	800°F (700 K)		
5-26	240	(1654.8)	100
5-18	220	(1516.9)	71,300
5-19	210	(1447.9)	124,600
5-20	200	(1379.0)	257,200
5-21	190	(1310.1)	476,100
5-22	180	(1241.1)	1,888,900
5-23	170	(1172.2)	5,212,700
5-24	160	(1103.2)	4,055,000
5-25	150	(1034.3)	8,824,100

(a) Did not fail.

TABLE C-8. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) AF1410 STEEL AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)		Cycles to Failure
	Room Temperature (RT)		
5N-1	200	(1379.0)	1,700
5N-2	170	(1172.2)	2,700
5N-3	140	(965.3)	3,200
5N-4	100	(689.5)	8,100
5N-25	80	(551.6)	23,300
5N-26	60	(413.7)	55,500
5N-5	50	(344.8)	93,000
5N-6	40	(275.8)	160,900
5N-7	30	(206.9)	329,300
5N-8	20	(137.9)	10,000,000[(a)]
	400°F (477 K)		
5N-24	90	(620.6)	9,600
5N-10	80	(551.6)	15,400
5N-11	70	(482.7)	24,800
5N-27	70	(482.7)	21,100
5N-13	65	(448.2)	22,800
5N-12	60	(413.7)	18,600
5N-18	60	(413.7)	10,000,000[(a)]
5N-9	50	(344.8)	10,000,000[(a)]
	800°F (700 K)		
5N-17	100	(689.5)	6,900
5N-16	90	(620.6)	10,300
5N-15	80	(551.6)	50,800
5N-14	70	(482.7)	514,800
5N-19	60	(413.7)	2,708,800
5N-20	55	(379.2)	1,856,700
5N-21	50	(344.8)	2,730,100
5N-22	45	(310.3)	4,874,000
5N-23	40	(275.8)	11,869,900[(a)]

(a) Did not fail.

TABLE C-9. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE (TRANSVERSE)

Specimen Number	Stress, Ksi (MPa)	Temperature, F (K)	0.1	0.2	0.5	1.0	2.0
3-9	200 (1379.0)	600 (588)	--	--	--	--	--
3-7	190 (1310.1)	600 (588)	--	0.2	10	175	870
3-5	175 (1206.6)	600 (588)	1.1	15	430	1940[a]	--
3-8	150 (1034.3)	600 (588)	63	550	5000[a]	--	--
3-1	175 (1206.6)	800 (700)	--	--	--	0.1	0.2
3-2	150 (1034.3)	800 (700)	0.1	0.2	0.75	2.1	4.9
3-3	100 (689.5)	800 (700)	1.7	7.5	42	115	195
3-4	60 (413.7)	800 (700)	15	80	350	790	1620[a]
3-6	25 (172.4)	800 (700)	155	475	4600[a]	--	--
3-10	15 (103.4)	800 (700)	665	3350[a]	--	--	--

TABLE C-9. Continued.

Specimen Number	Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches (50.8mm) percent	Reduction of Area, percent	Minimum Creep Rate, percent
3-9	--	On loading	10.0	66.0	--
3-7	1.013	2465.3	13.8	70.5	0.0014
3-5	0.835	1515.9[b]	1.696	--	0.00030
3-8	0.858	2993.8[b]	1.246	--	0.000054
3-1	1.408	0.3	13.8	66.6	8.0
3-2	0.807	11.1	15.4	49.0	0.35
3-3	0.461	328.1	10.8	13.4	0.0064
3-4	0.254	961.3[b]	1.422	--	0.0011
3-6	0.161	2328.8[b]	0.534	--	0.00005
3-10	0.085	2015.4[b]	0.246	--	0.000032

(a) Estimated.

(b) Test discontinued.

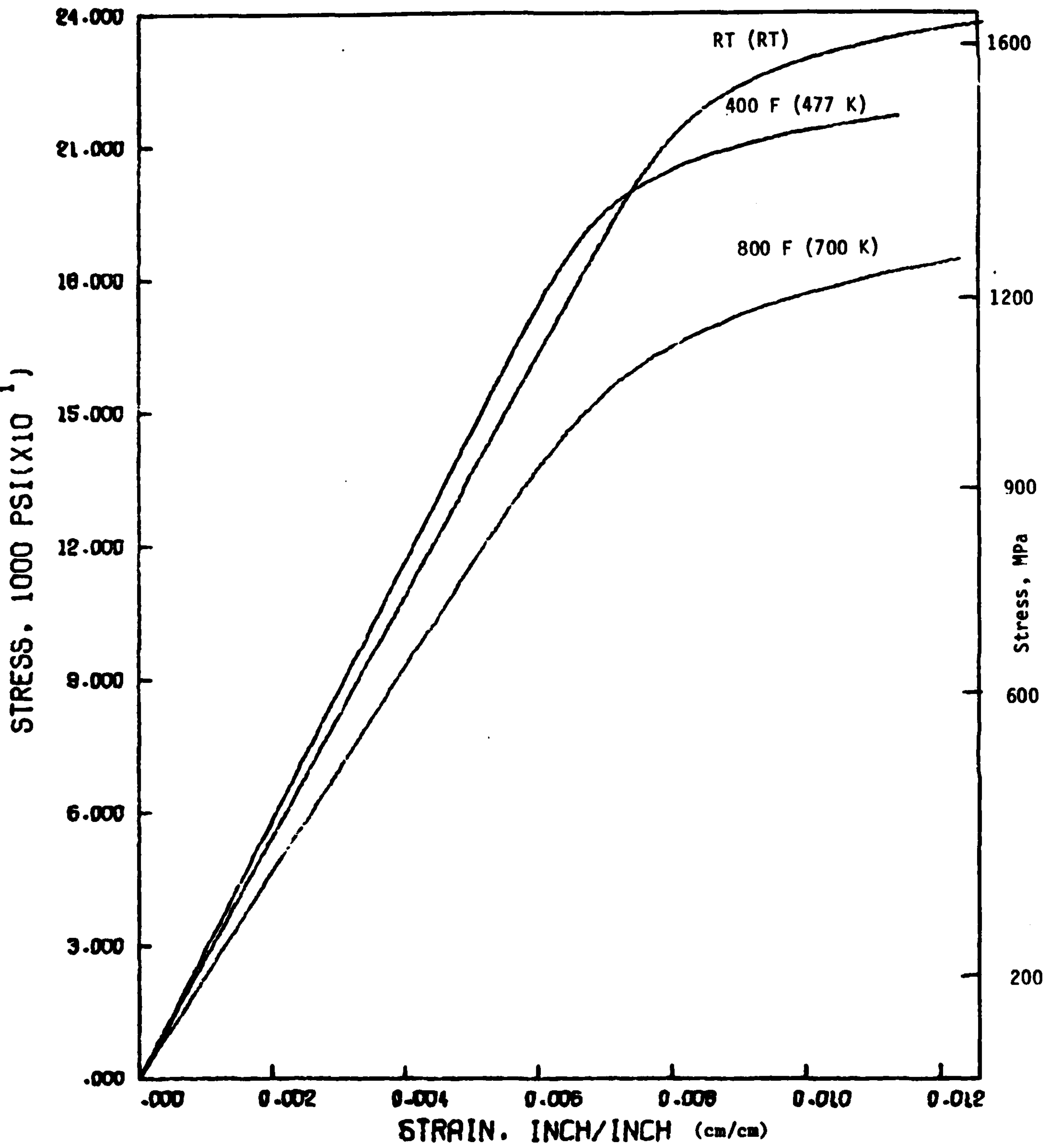


FIGURE C-2. TYPICAL TENSILE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

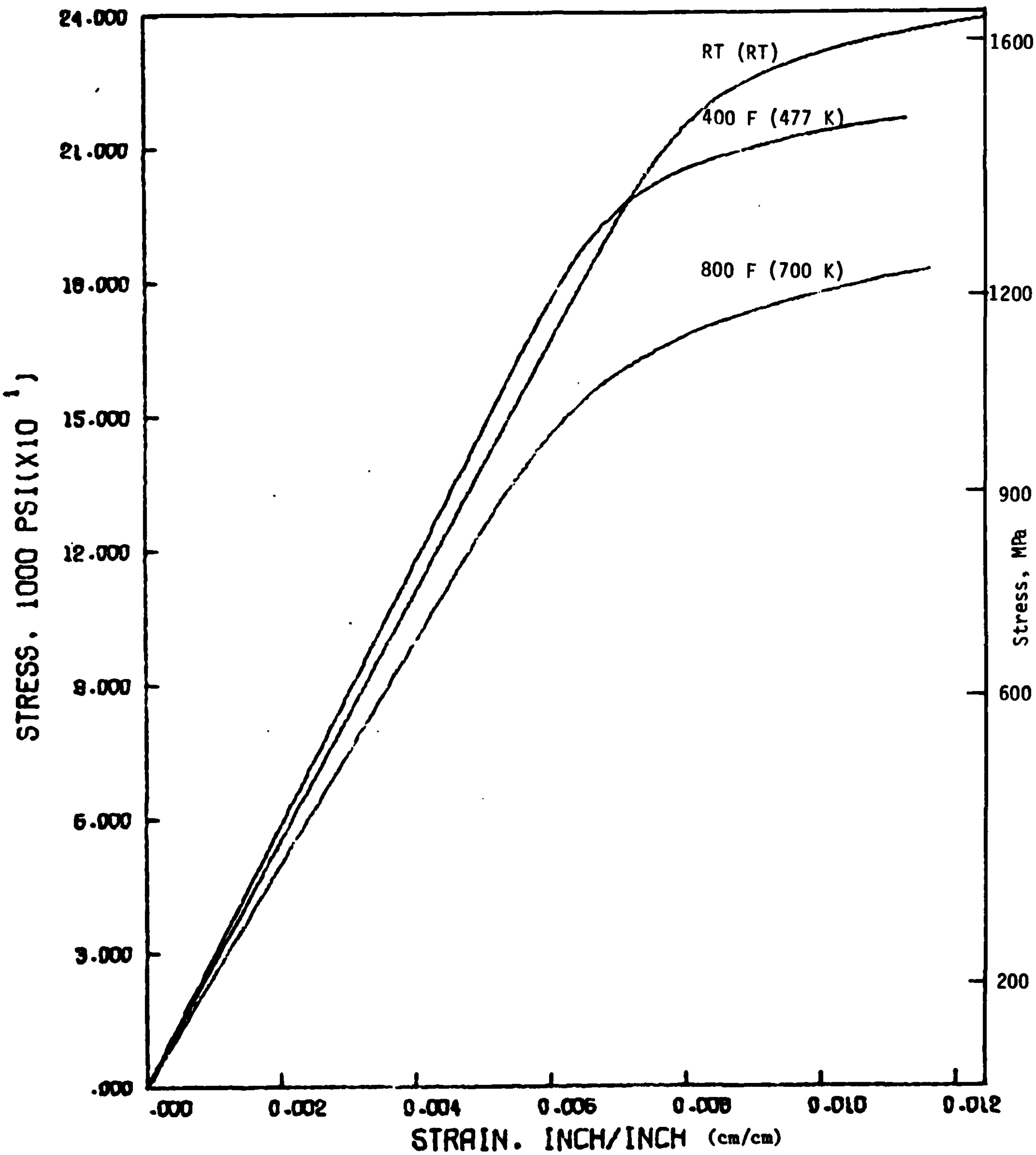


FIGURE C-3. TYPICAL TENSILE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

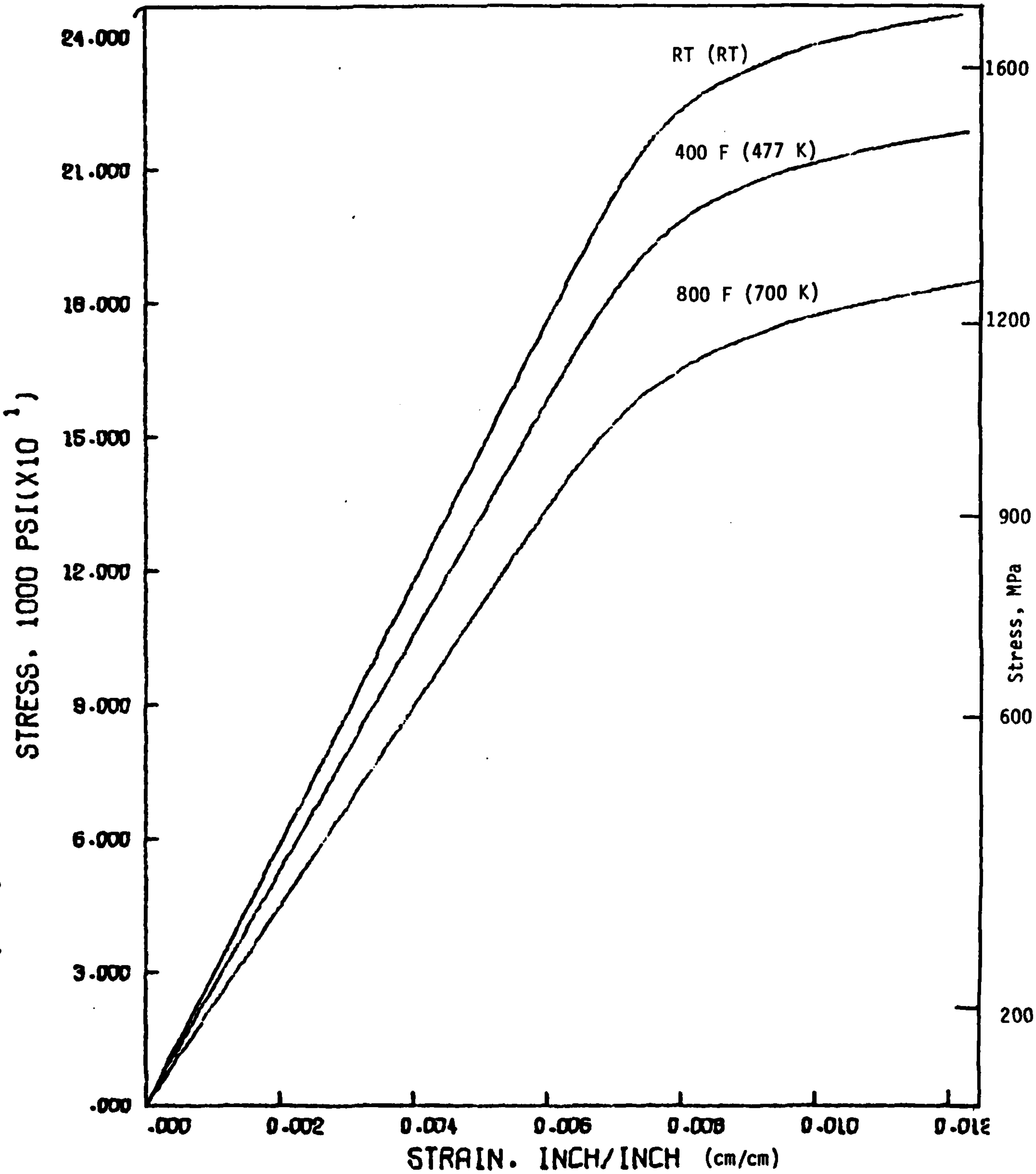


FIGURE C-4. TYPICAL COMPRESSIVE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

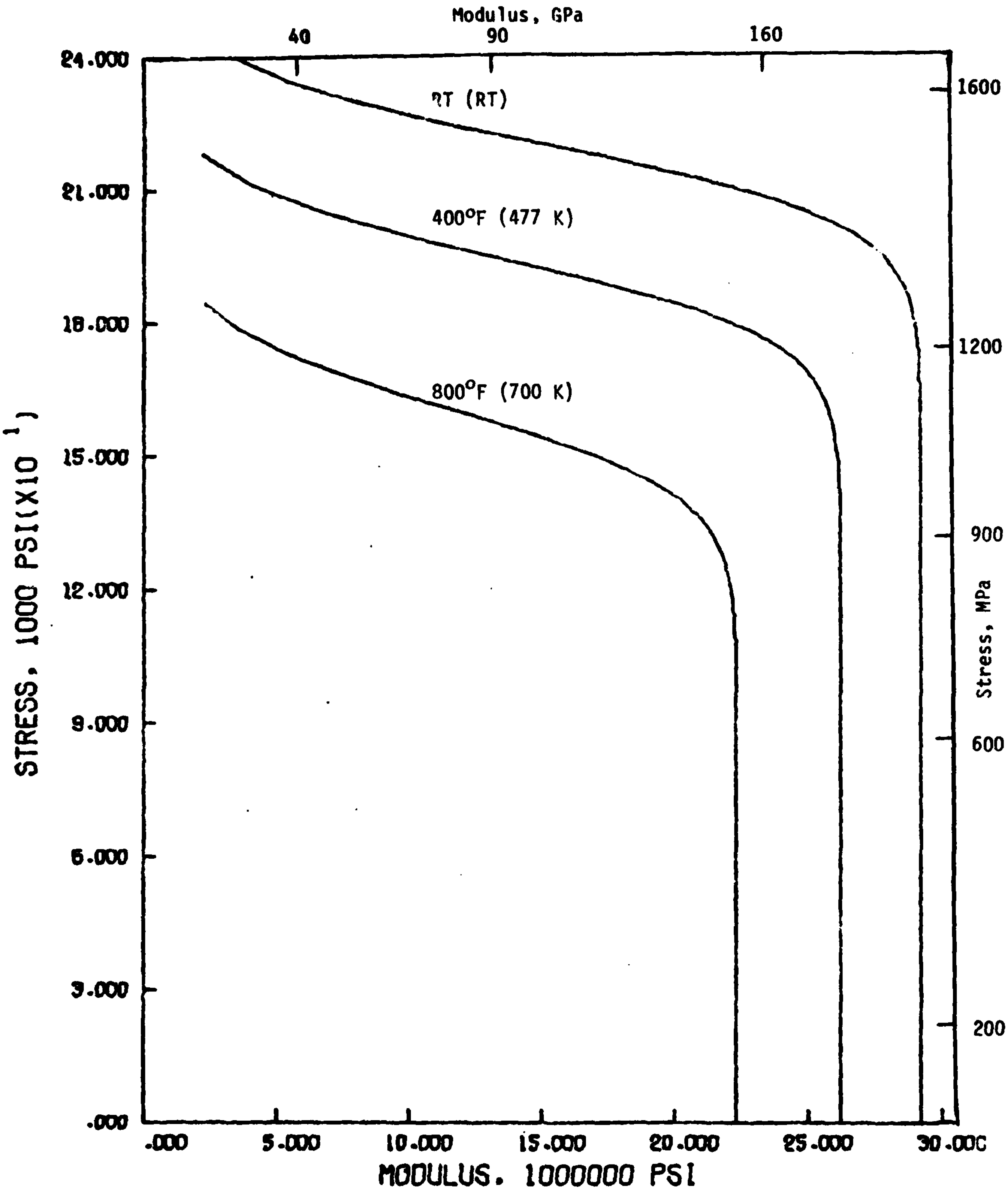


FIGURE C-5. TYPICAL COMPRESSIVE LONGITUDINAL TANGENT-MODULUS CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

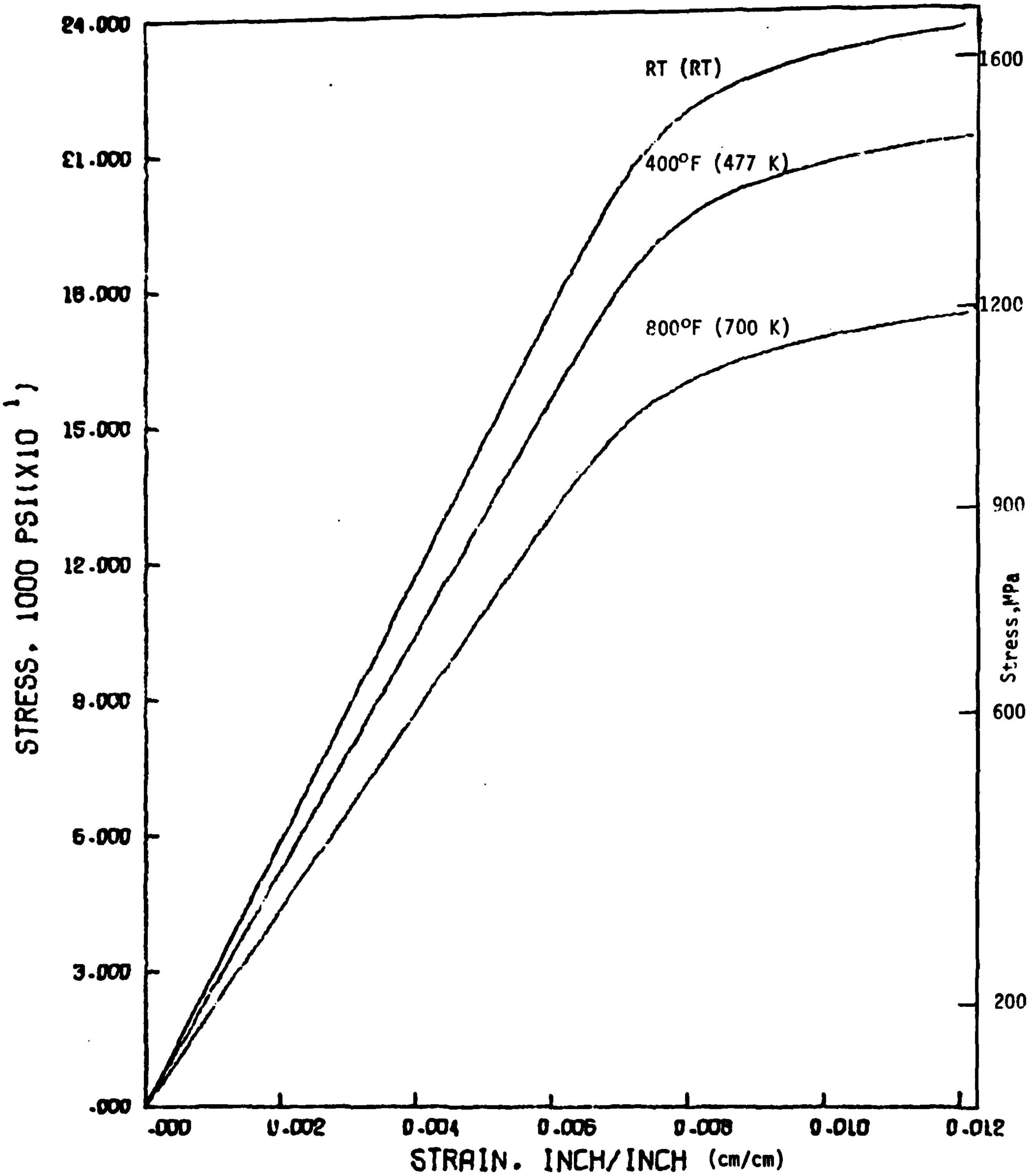


FIGURE C-6. TYPICAL COMPRESSIVE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

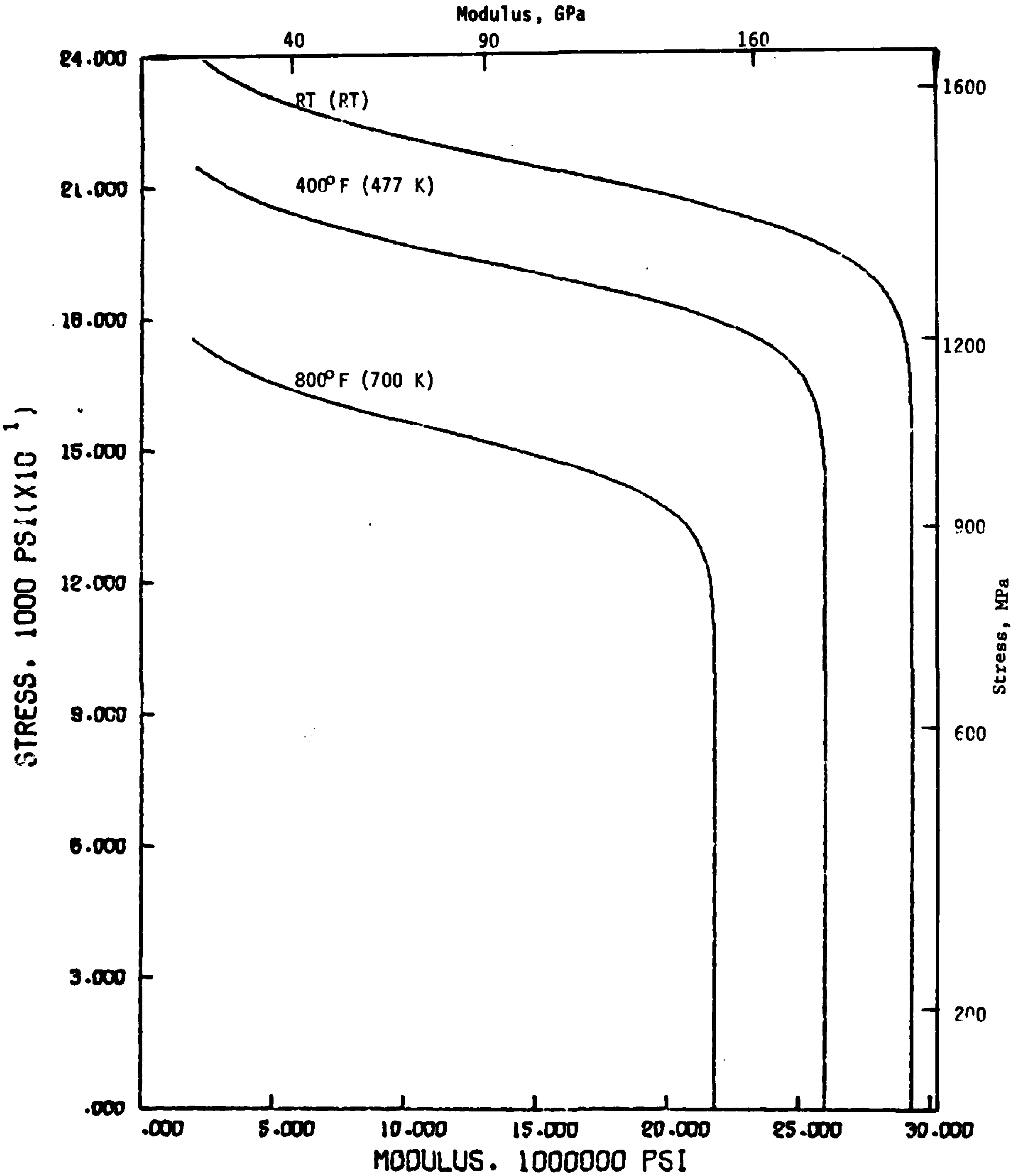


FIGURE C-7. TYPICAL COMPRESSIVE TRANSVERSE TANGENT-MODULUS CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 STEEL PLATE

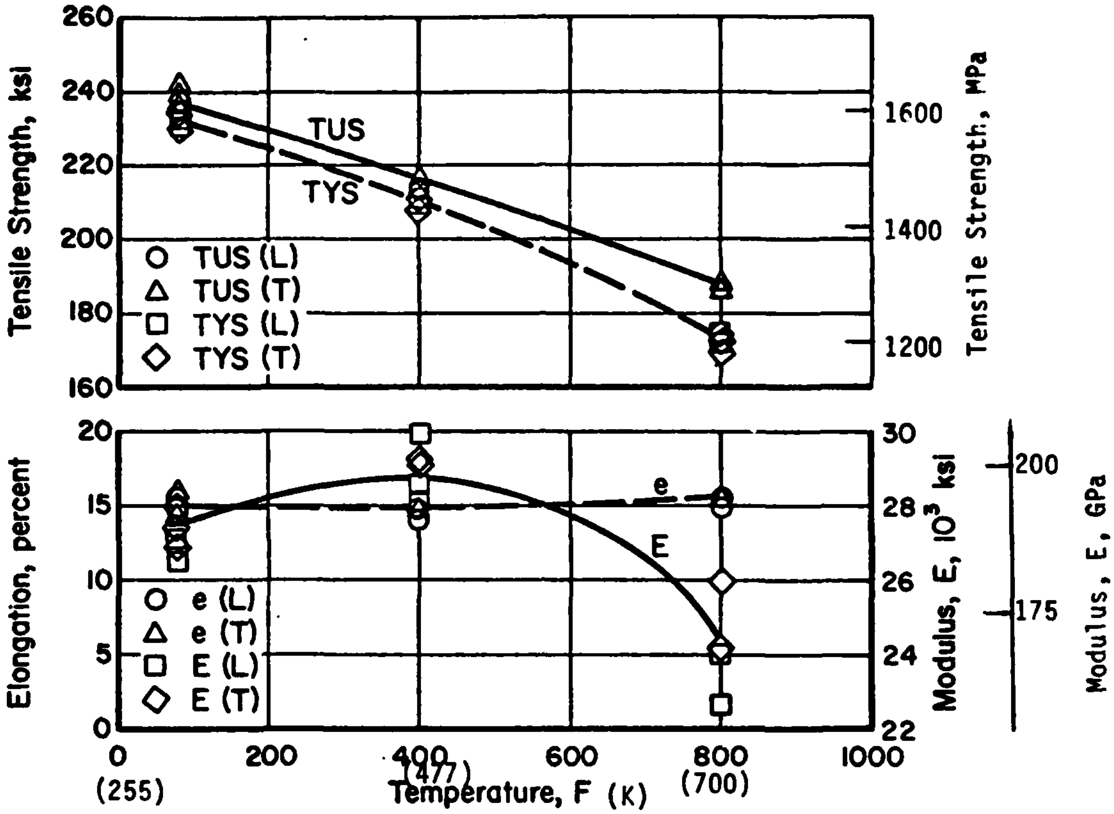


FIGURE C-8. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

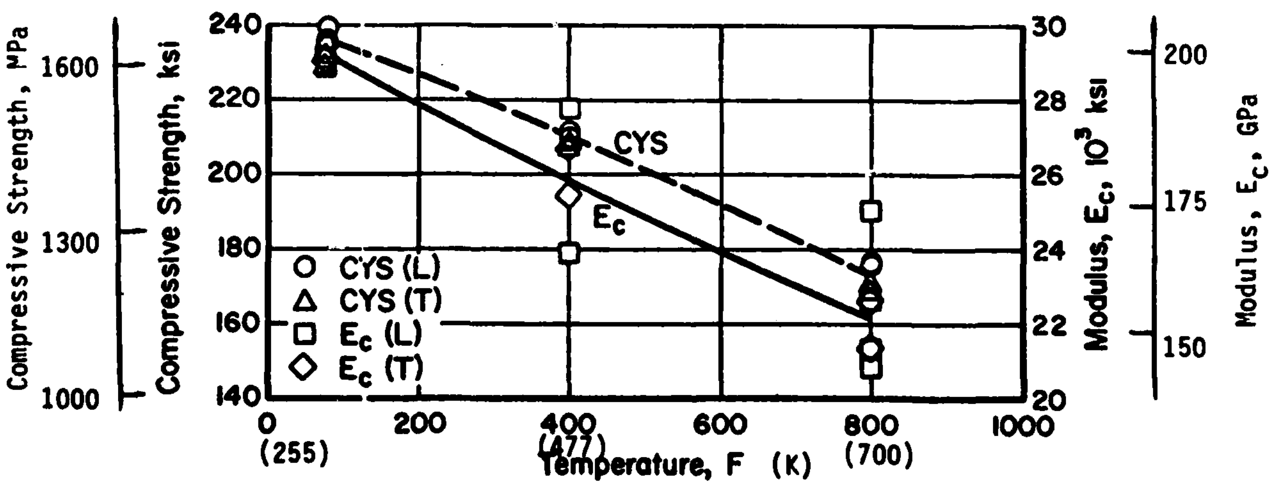


FIGURE C-9. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

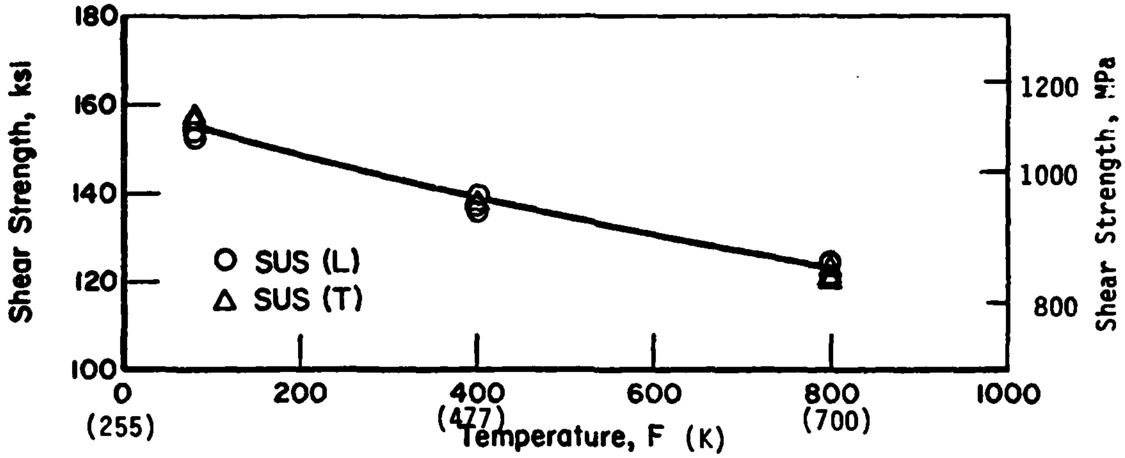


FIGURE C-10. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

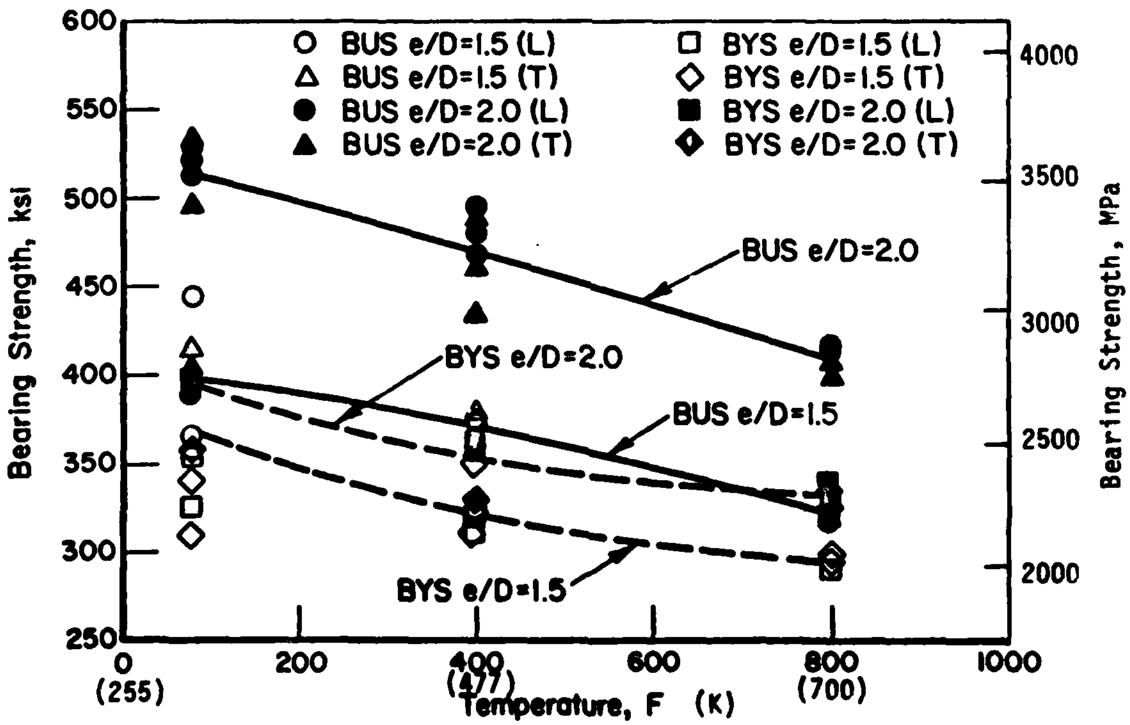


FIGURE C-11. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

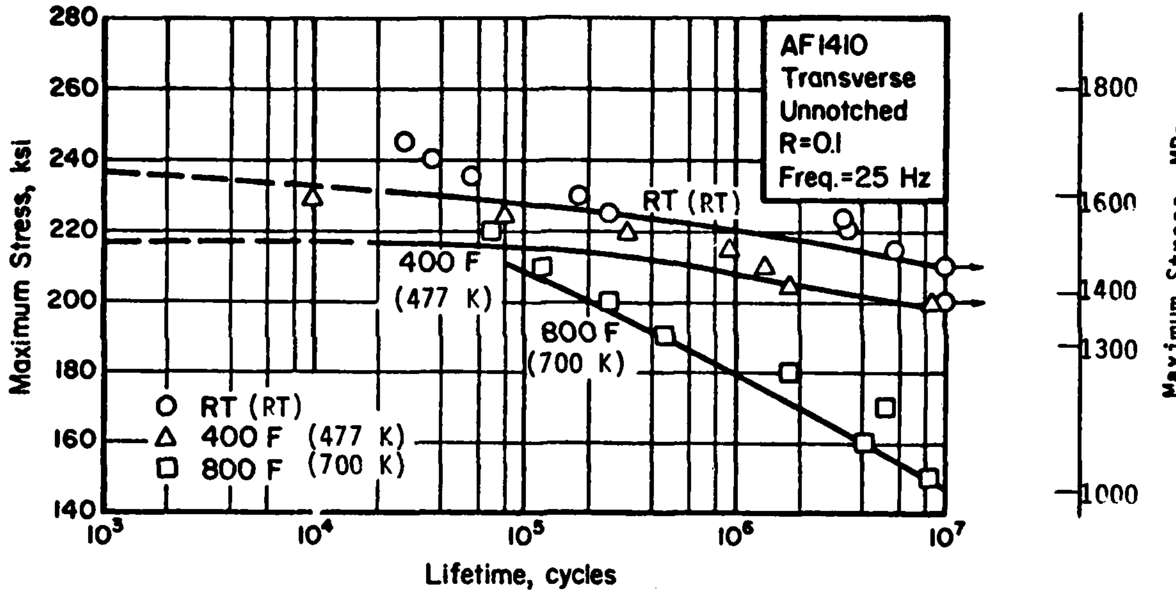


FIGURE C-12. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

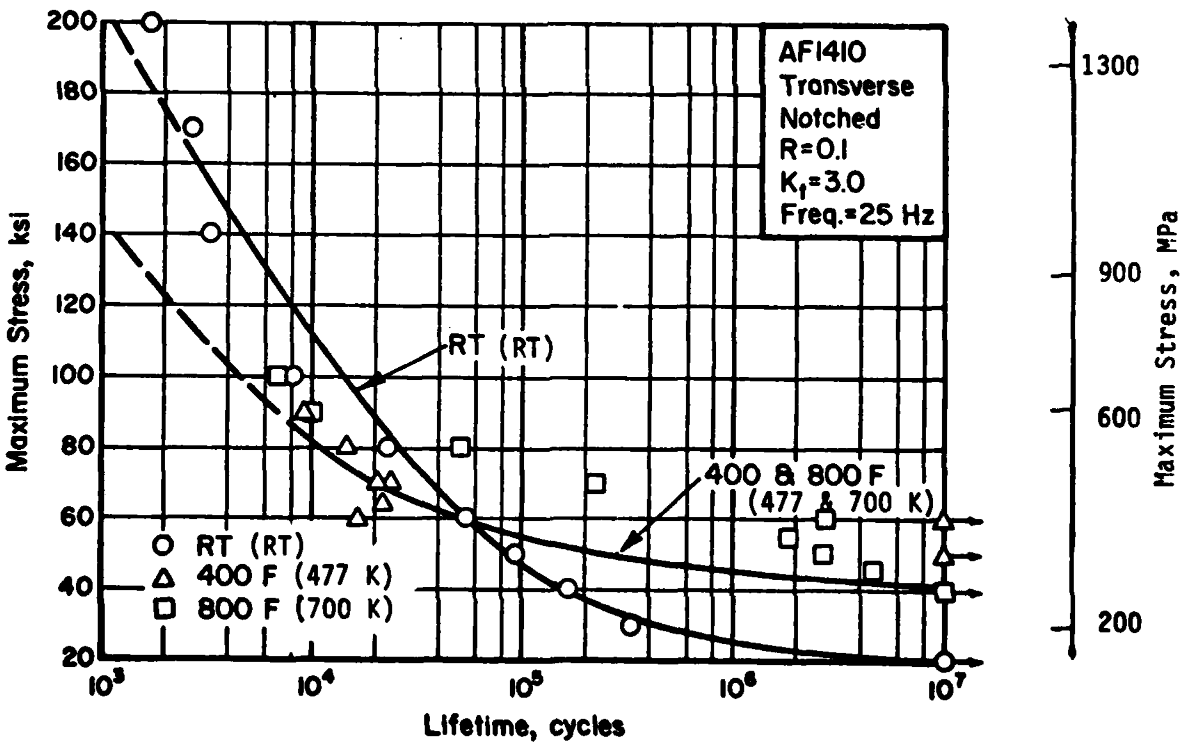


FIGURE C-13. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

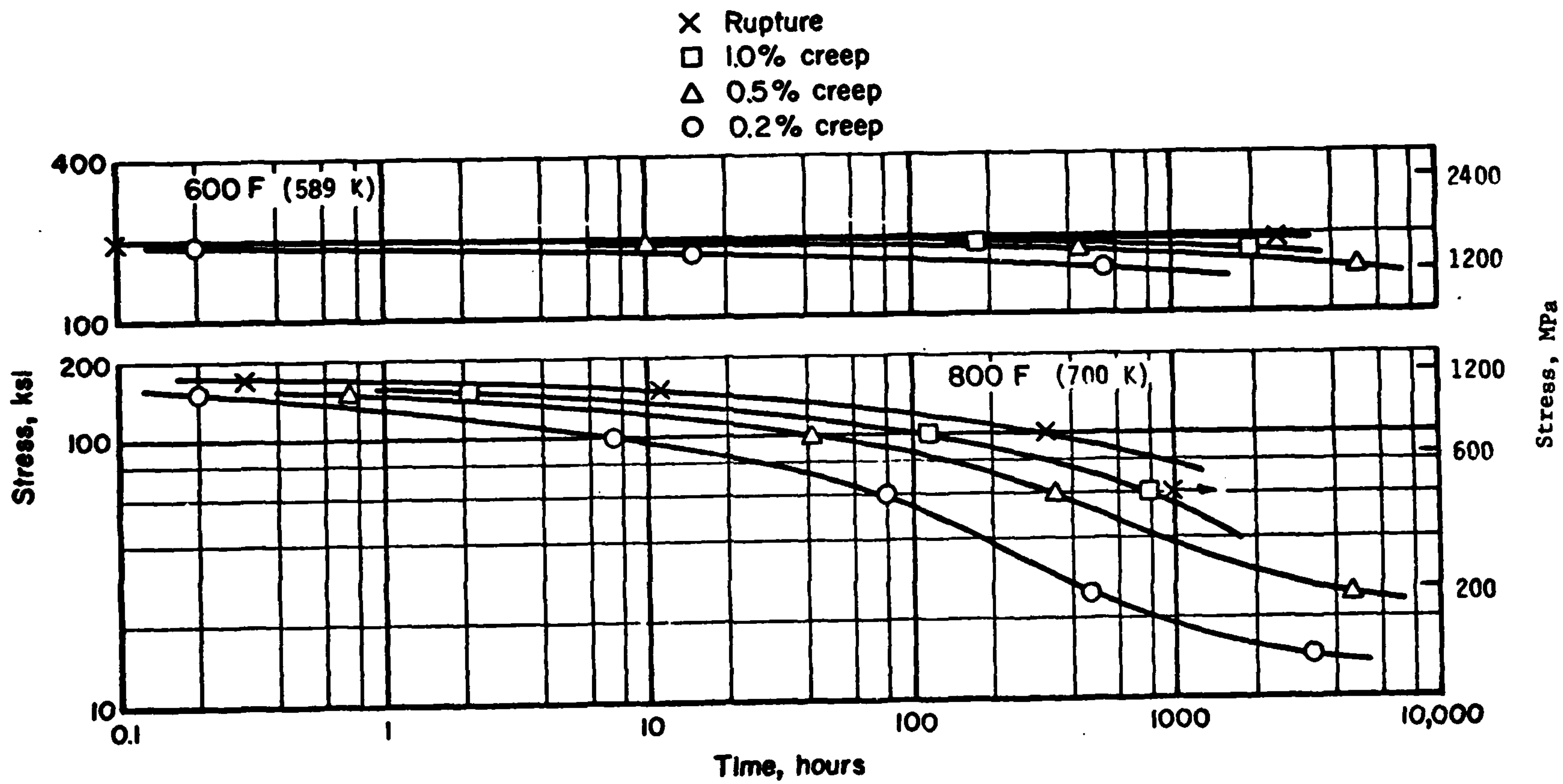


FIGURE C-14. CREEP RUPTURE AND PLASTIC DEFORMATION CURVES FOR TRANSVERSE AF 1410 STEEL PLATE

AF 1410 Die Forging

Material Description

This material is from the same development program described in the preceding section on AF 1410 steel plate. It is from the same heat of material and processing and development history may be obtained from the AFML Technical Report mentioned in the section on steel plate.

Processing and Heat Treating

Prior heat treating information for the particular piece of material used on this program was somewhat vague, so the forging was given the full double-austenitize and age recommended for the steel plate. This was 1650°F (1172 K), water quench, plus 1550°F (116K), water quench, and age at 950°F (783 K) for 5 hours with a rapid air cool.

A photograph of the forging is shown in Figure C-15. All specimens were sectioned in the longitudinal (length) direction.

Test Results

Tension. Results of longitudinal tests at room temperature, 400°F (477 K), and 800°F (700 K) are given in Table C-10. Typical stress-strain curves at temperature are presented in Figure C-16. Effect-of-temperature curves are shown in Figure C-19.

Compression. Results of longitudinal compression tests at room temperature, 400°F (477 K), and 800°F (700 K) are given in Table C-11. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures C-17 and C-18. Effect-of-temperature curves are presented in Figure C-20.

Shear. Results of double-shear pin type tests at room temperature, 400°F (477 K), and 800°F (700 K) are given in Table C-12. Effect-of-temperature curves are presented in Figure C-21.

Bearing. The material was not of sufficient size to obtain bearing specimens.

Impact. Results of impact tests at room temperature are given in Table C-13.

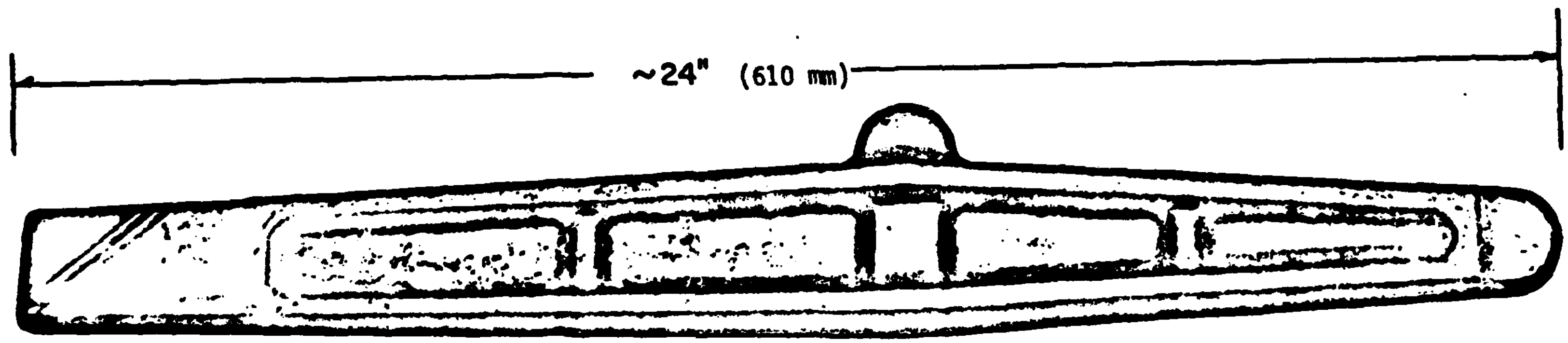


FIGURE C-15. AF 1410 STEEL DIE FORGING

Fracture Toughness. The material was not of sufficient size to obtain fracture specimens.

Fatigue. Because of the shape and quantity of available material, only room-temperature unnotched and notched specimens were obtained. Results of these tests are given in Table C-14. S-N curves are presented in Figure C-22.

Stress Corrosion. Since K_{Iscc} tests were somewhat unsuccessful on the AF 1410 plate, stress-corrosion tests as described in the experimental procedures section of this report were conducted on this forging. No cracks or failures occurred in the test duration.

Thermal Expansion and Density. It is assumed these properties are similar to those reported for the AF 1410 plate.

TABLE C-10. RESULTS OF LONGITUDINAL TENSILE TESTS FOR AF 1410 STEEL DIE FORGINGS

Specimen Number	Ultimate Tensile Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 1 Inch, (25.4mm) percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi (GPa)
		Room Temperature			
1L-1	236.2 (1628.6)	232.0 (1599.6)	15.0	69.9	27.6 (190.3)
1L-2	230.0 (1585.9)	227.7 (1570.0)	16.0	63.7	29.9 (206.2)
1L-3	231.8 (1598.3)	228.0 (1572.1)	14.0	60.1	30.0 (206.9)
Average	232.6 (1603.8)	229.9 (1585.2)	15.0	64.6	29.2 (201.3)
		400°F			
1L-4	209.9 (1447.3)	203.6 (1403.8)	14.0	63.6	28.1 (193.8)
1L-5	208.0 (1434.2)	202.0 (1392.8)	13.0	59.7	26.5 (182.7)
1L-6	210.1 (1448.6)	200.0 (1379.0)	15.0	63.0	29.0 (200.0)
Average	209.3 (1443.1)	201.9 (1392.1)	14.0	62.1	27.9 (192.4)
		800°F			
1L-7	180.1 (1241.8)	170.1 (1172.8)	16.0	70.2	24.0 (165.5)
1L-8	179.8 (1239.7)	172.0 (1185.9)	16.0	69.2	26.0 (179.3)
1L-9	183.7 (1266.6)	171.1 (1179.7)	16.0	67.3	25.8 (177.9)
Average	181.2 (1249.4)	171.1 (1179.7)	16.0	68.9	25.3 (174.4)

TABLE C-11. RESULTS OF LONGITUDINAL COMPRESSION TESTS FOR AF 1410 STEEL DIE FORGINGS

Specimen Number		0.2 Percent Offset Yield Strength, ksi (MPa)		Compressive Modulus 10^3 ksi (GPa)	
		Room Temperature (RT)			
2L-1		230.7	(1590.7)	29.0	(200.0)
2L-2		228.8	(1577.6)	30.4	(209.6)
2L-3		230.1	(1586.5)	29.7	(204.8)
	Average	229.9	(1585.2)	29.7	(204.8)
		400°F (477 K)			
2L-4		200.8	(1384.5)	24.4	(168.2)
2L-5		202.3	(1394.9)	28.8	(198.6)
2L-6		200.1	(1379.7)	28.3	(195.1)
	Average	201.1	(1386.6)	27.2	(187.5)
		800°F (700 K)			
2L-7		165.0	(1137.7)	25.0	(172.4)
2L-8		169.5	(1168.7)	26.1	(179.9)
2L-9		168.7	(1163.2)	23.7	(163.4)
	Average	167.7	(1156.3)	24.9	(171.7)

TABLE C-12. RESULTS OF LONGITUDINAL PIN SHEAR TESTS ON AF 1410 STEEL DIE FORGINGS

Specimen Number		Shear Ultimate Strength, ksi	(MPa)
	Room Temperature (RT)		
4L-1		135.5	(934.3)
4L-2		133.9	(923.2)
4L-3		135.3	(932.9)
	Average	134.9	(930.1)
	400°F (477 K)		
4L-4		118.2	(814.9)
4L-5		118.6	(817.8)
4L-6		119.1	(821.2)
	Average	118.6	(817.8)
	800°F (700 K)		
4L-7		101.5	(699.8)
4L-8		101.5	(699.8)
4L-9		98.7	(680.5)
	Average	100.6	(693.6)

TABLE C-13. RESULTS OF LONGITUDINAL CHARPY IMPACT TESTS AT ROOM TEMPERATURE ON AF 1410 STEEL DIE FORGINGS

Specimen Number		Energy, ft lbs	(Joules)
10L-1		8	(10.8)
10L-2		12	(16.3)
10L-3		10	(13.6)
10L-4		9	(12.2)
10L-5		12	(16.3)
10L-6		10	(13.6)
	Average	10.2	(13.8)

TABLE C-14. RESULTS OF AXIAL LOAD FATIGUE TESTS AT ROOM TEMPERATURE FOR UNNOTCHED AND NOTCHED (K_t = 3.0) AF 1410 STEEL DIE FORGING AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)	Cycles to Failure
	Unnotched	
5-1	225 (1551.4)	12,600
5-2	210 (1448.0)	14,300
5-9	200 (1379.0)	37,100
5-3	195 (1344.5)	77,200 [a]
5-4	195 (1344.5)	285,000 [a]
5-5	195 (1344.5)	1,774,200 [a]
5-6	185 (1275.6)	148,700
5-8	180 (1241.1)	39,900 [a]
5-10	180 (1241.1)	4,365,000 [a]
5-7	175 (1206.6)	10,000,000 [b]
	Notched (K_t = 3.0)	
5-11	100 (689.5)	1,600
5-12	60 (413.7)	16,600
5-13	50 (344.8)	20,500
5-17	45 (310.3)	13,600 [a]
5-16	40 (275.8)	87,800
5-18	35 (241.3)	50,400 [a]
5-14	30 (206.9)	258,400
5-21	25 (172.4)	303,200
5-15	20 (137.9)	10,000,000 [b]

(a) Failed in grip.

(b) Did not fail.

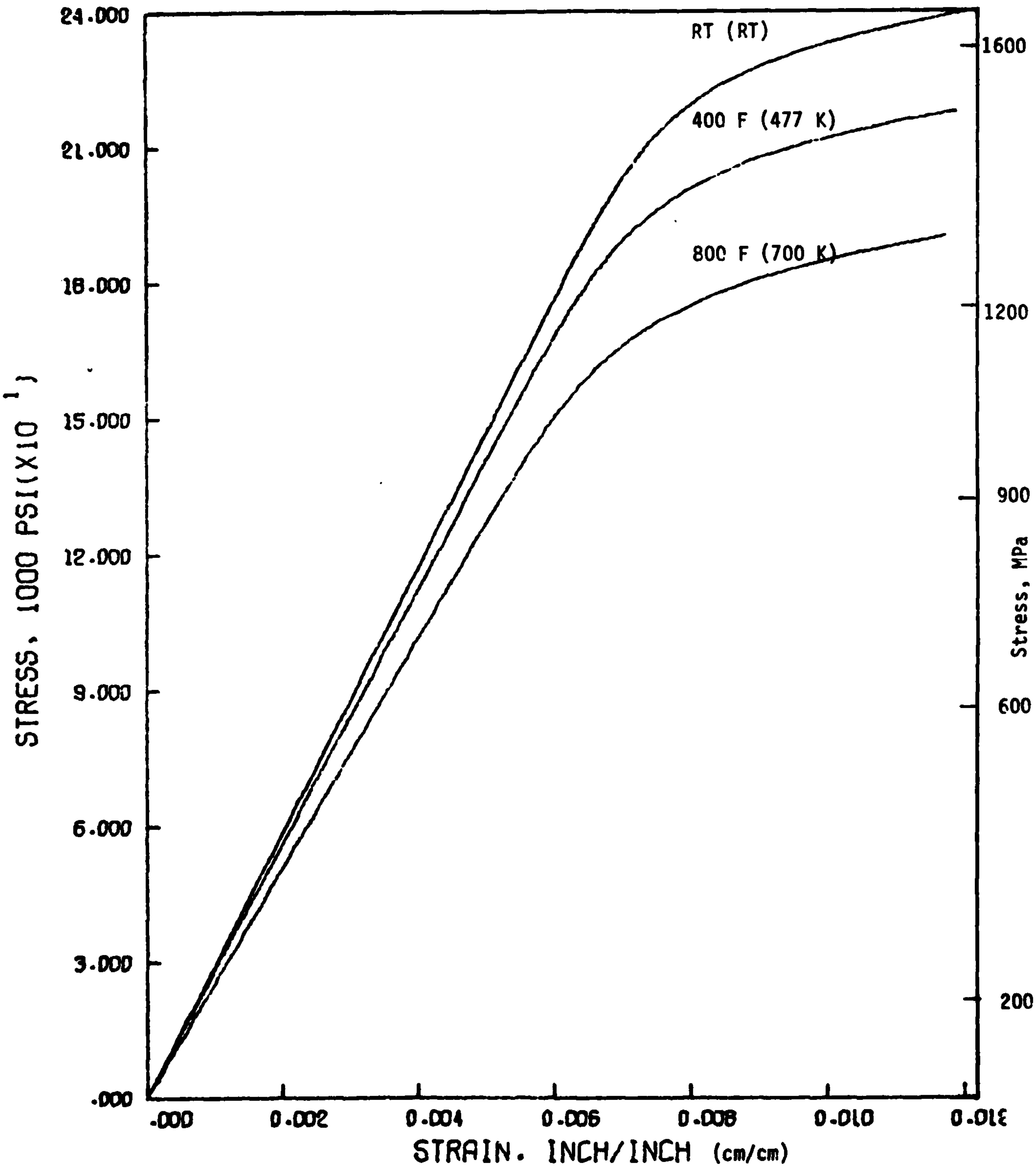


FIGURE C-16. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE AUSTENITIZED AND AGED AF 1410 DIE FORGINGS

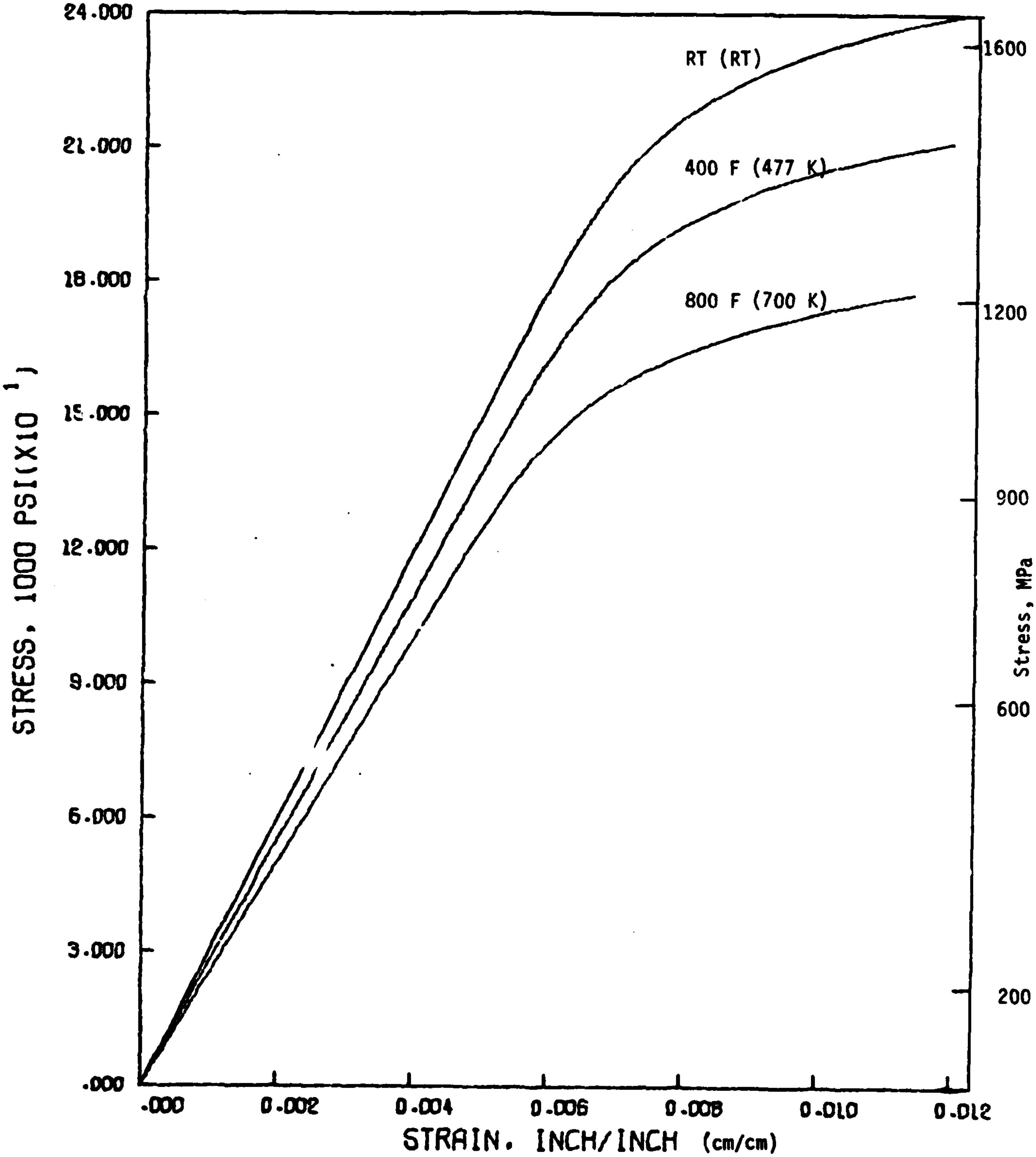


FIGURE C-17. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR DOUBLE-AUSTENITIZED AND AGED AF 1410 DIE FORGINGS

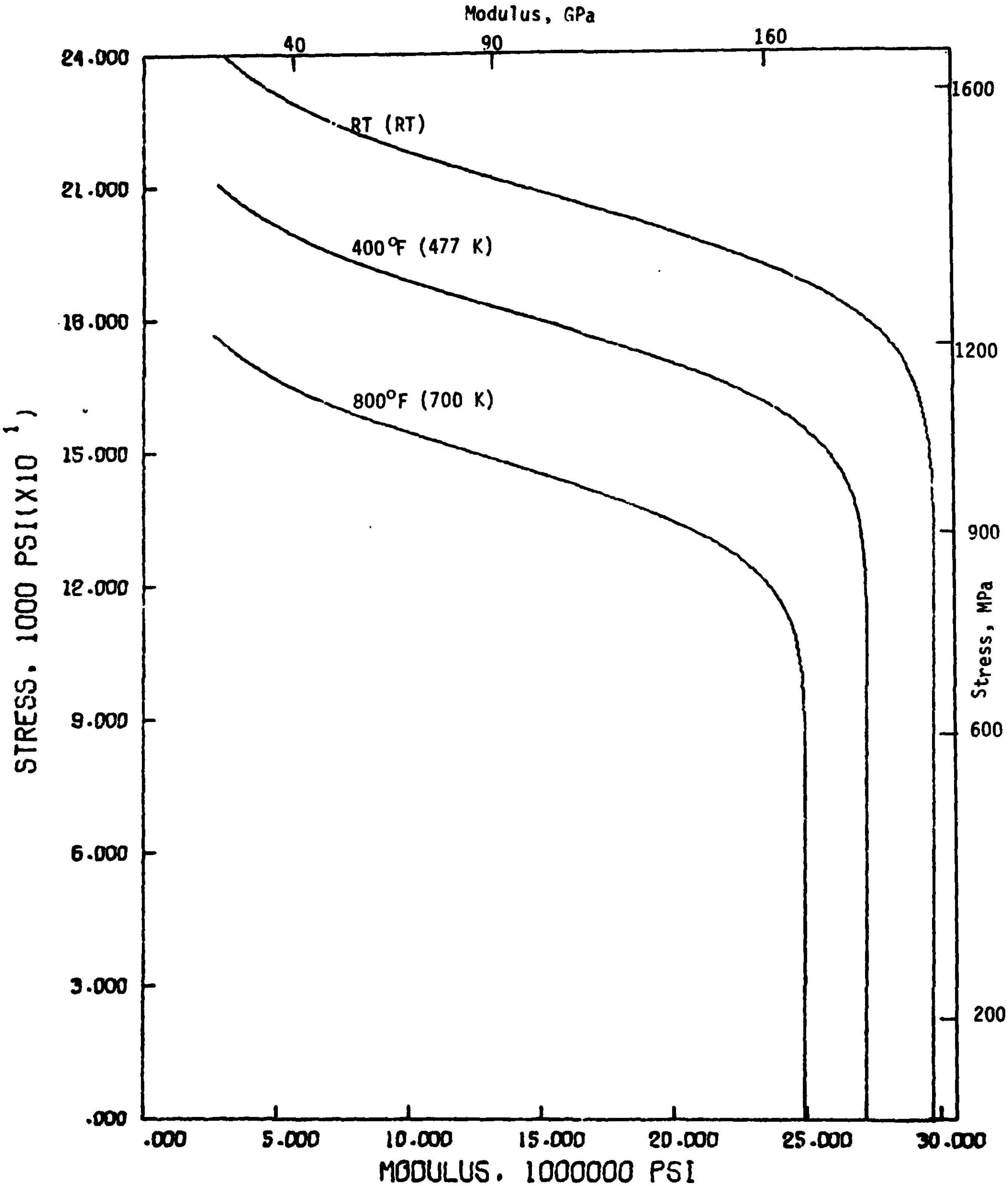


FIGURE C-18. TYPICAL CO**RESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR DOUBLE-AUST**ITIZED AND AGED AF 1410 DIE FORGING

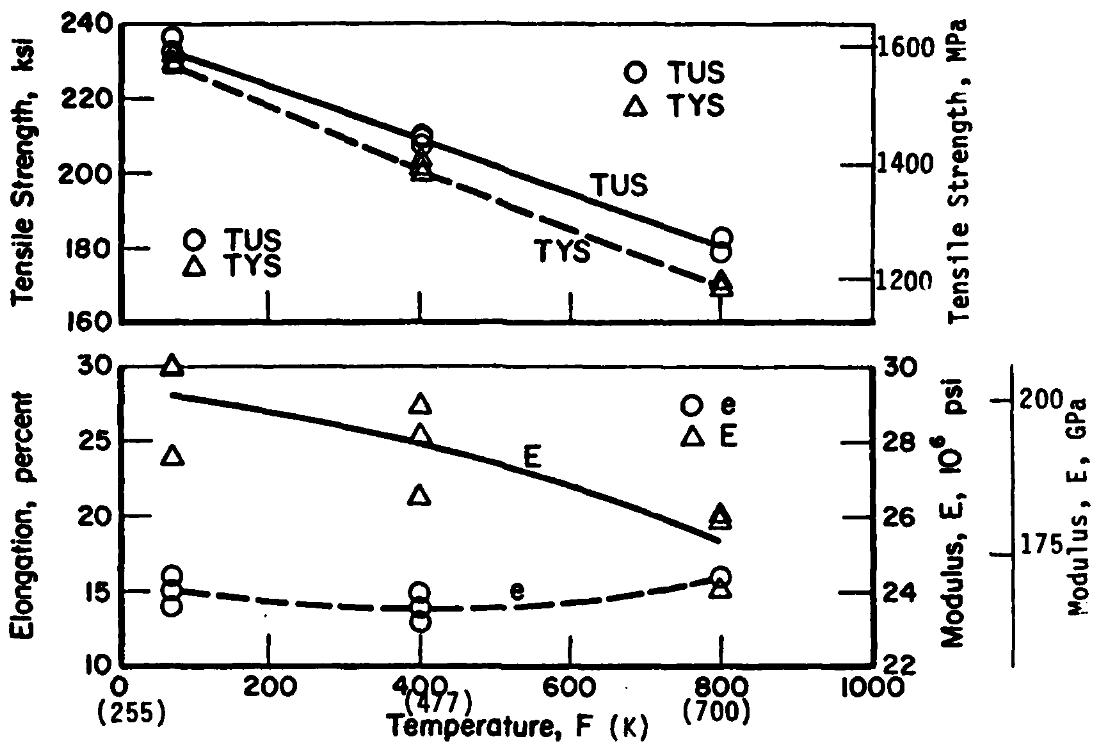


FIGURE C-19. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF 1410 DIE FORGINGS

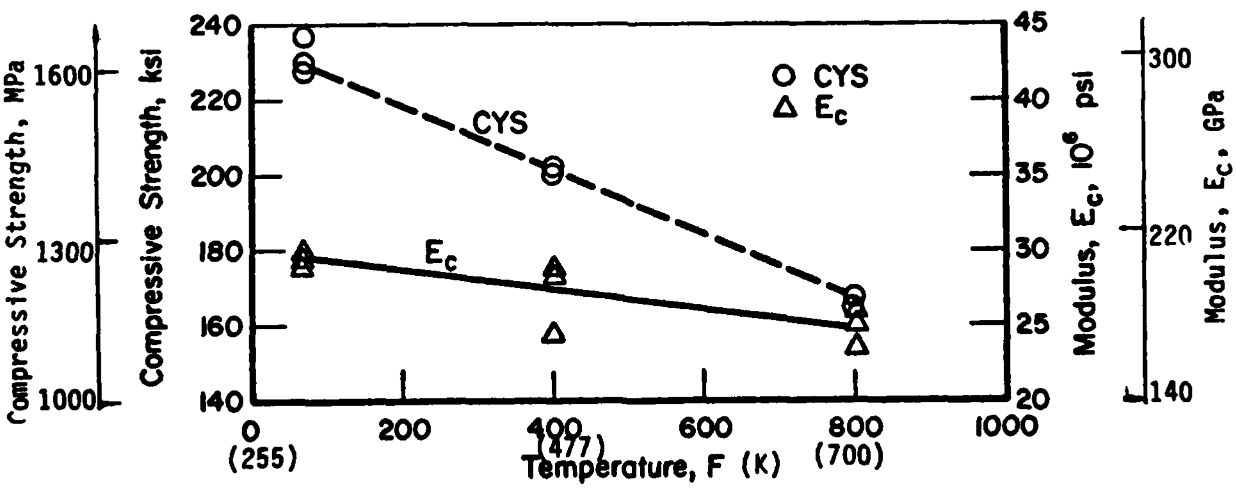


FIGURE C-20. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF 1410 DIE FORGINGS

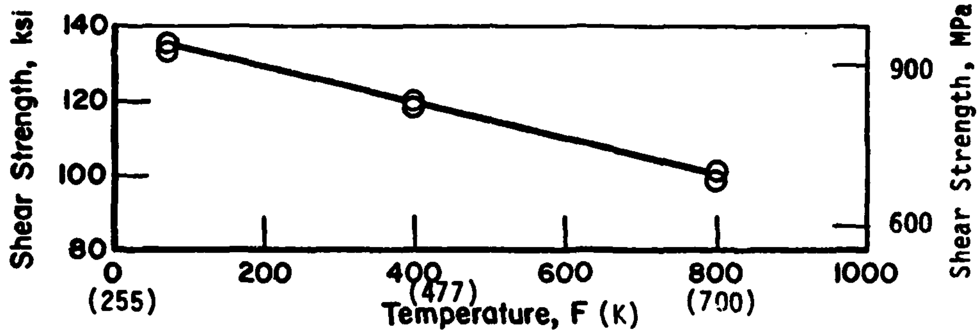


FIGURE C-21. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF AF 1410 DIE FORGINGS

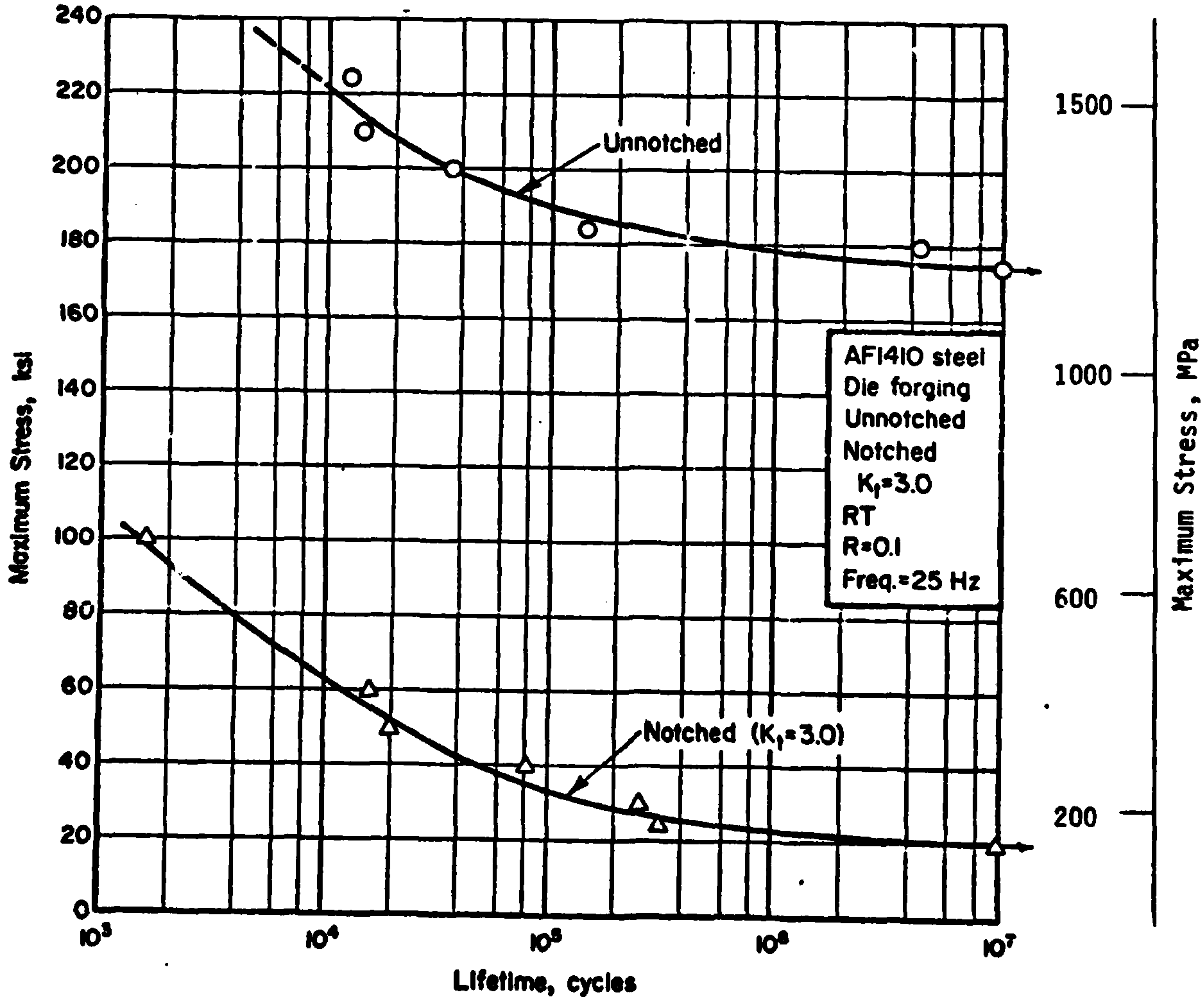


FIGURE C-22. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED AND NOTCHED AF 1410 DIE FORGINGS AT ROOM TEMPERATURE

MECHANICAL-PROPERTY DATA
AF 1410 (10Ni Modified) STEEL

DOUBLE AUSTENITIZED AND AGED PLATE

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-75-C-5065

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-75-C-5065. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Dr. David Snediker. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth, Technical Manager, Engineering and Design Data.

Notices

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any potential invention that may be in any way related thereto.

Approved for public release; distribution unlimited.

Copies of this report should not be returned unless return is required by security consideration, contractual obligations, or notice on a specific document.

AF 1410 Steel

Material Description

This material is the result of a cooperative development program by General Dynamics and U.S. Steel under the sponsorship of the Air Force Materials Laboratory. The development requirement was for a weldable high strength steel alloy, possessing a combined high fracture toughness and stress corrosion resistance.

Considerable information and additional data for AF 1410 is contained in the final report on Contract F33615-73C-5093, AFML-TR-75-148, "Development of a Weldable High Strength Steel", September, 1975.

The material used in this evaluation was plate from Heat 9 which is described in the above report.

Processing and Heat Treating

The plate was received in a double-austenitized condition. Specimens were aged at 950°F (783.2K) for 5 hours and air cooled.

AF 1410 Steel Alloy Data[a]

Condition: Double Austenitized and Aged
Thickness: 1.25-inch (31.75mm) plate

Properties	RT	(RT)	400	(477)	800	(700)
	Temperature, F (K)					
Tension						
TUS (longitudinal), ksi (MPa)	236.6	(1631.4)	213.8	(1474.2)	186.5	(1285.9)
TUS (transverse), ksi (MPa)	240.1	(1655.5)	216.6	(1493.5)	187.6	(1293.5)
TYS (longitudinal), ksi (MPa)	232.5	(1603.1)	211.2	(1456.2)	174.8	(1205.3)
TYS (transverse), ksi (MPa)	232.7	(1604.5)	210.3	(1450.0)	172.7	(1190.8)
e (longitudinal), percent in 1 in. (25.4 mm)		15.2		14.7		15.7
e (transverse), percent in 1 in. (25.4 mm)		15.2		15.0		16.0
RA (longitudinal), percent		63.4		68.5		68.6
RA (transverse), percent		65.1		67.3		67.3
E (longitudinal), 10^3 ksi (GPa)	27.1	(186.6)	29.0	(199.9)	23.1	(159.3)
E (transverse), 10^3 ksi (GPa)	27.5	(189.6)	29.1	(200.6)	24.8	(171.0)
Compression						
CYS (longitudinal), ksi (MPa)	238.4	(1643.8)	211.3	(1456.9)	176.6	(1218.3)
CYS (transverse), ksi (MPa)	233.1	(1607.2)	208.8	(1439.7)	169.4	(1168.0)
E_c (longitudinal). 10^3 ksi (GPa)	29.2	(201.3)	26.2	(180.6)	22.3	(153.)
E_c (transverse), 10^3 ksi (GPa)	29.3	(202.0)	26.0	(179.3)	21.8	(150.3)
Bearing						
e/D = 1.5						
BUS (longitudinal), ksi (MPa)	395.0	(2723.5)	373.6	(2575.9)	322.5	(2223.6)
BUS (transverse), ksi (MPa)	390.0	(2689.1)	370.5	(2554.6)	321.7	(2218.1)
BYS (longitudinal), ksi (MPa)	343.0	(2364.9)	322.7	(2225.0)	294.2	(2028.5)
BYS (transverse), ksi (MPa)	336.3	(2318.8)	321.5	(2216.7)	294.6	(2031.3)
e/D = 2.0						
BUS (longitudinal), ksi (MPa)	521.9	(3598.5)	482.0	(3323.4)	413.2	(2849.0)
BUS (transverse), ksi (MPa)	514.8	(3549.5)	461.8	(3184.1)	405.9	(2798.6)
BYS (longitudinal), ksi (MPa)	394.1	(2717.3)	363.7	(2507.7)	335.9	(2316.0)
BYS (transverse), ksi (MPa)	395.1	(2724.2)	351.1	(2420.8)	333.1	(2296.7)
Shear[b]						
SUS (longitudinal), ksi (MPa)	154.7	(1066.6)	138.9	(957.7)	124.6	(859.1)
SUS (transverse), ksi (MPa)	156.0	(1075.6)	138.0	(951.5)	122.6	(845.3)
Impact						
V-notch Charpy, ft.lbs. (Joules)						
(longitudinal)	41.0	(55.6)	U[c]		U	
(transverse)	42.0	(56.9)	U		U	

AF 1410 Steel Alloy Data (Continued)

Properties	RT	(RT)	Temperature, F (K) 400	(477)	800	(700)
Fracture Toughness[d]						
K_{Ic} (longitudinal), ksi$\sqrt{in}$ (MPa$\sqrt{m}$)	130.5	(143.4)	U		U	
K_{Ic} (transverse), ksi$\sqrt{in}$ (MPa$\sqrt{m}$)	127.1	(139.7)	U		U	
Axial Fatigue (transverse)						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	240	(1654.8)	216	(1489.3)	186	(1282.5)
10^5 cycles, ksi (MPa)	228	(1572.1)	215	(1482.4)	186	(1282.5)
10^7 cycles, ksi (MPa)	210	(1447.9)	200	(1379.0)	145	(999.8)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	200	(1379.8)	140	(965.3)	140	(965.3)
10^5 cycles, ksi (MPa)	50	(344.8)	55	(379.2)	55	(379.2)
10^7 cycles, ksi (MPa)	20	(137.9)	40	(275.8)	40	(275.8)
	RT	(RT)	600	(589)	800	(700)
Creep (transverse)						
0.2% plastic deformation, 100 hr ksi (MPa)	NA		162	(1117.0)	54	(372.3)
0.2% plastic deformation, 1000 hr ksi (MPa)	NA		143	(985.8)	19	(131.0)
Stress Rupture (transverse)						
Rupture, 100 hr, ksi (MPa)	NA		194	(1337.6)	120	(827.4)
Rupture, 1000 hr, ksi (MPa)	NA		192	(1323.8)	77	(530.9)
Stress Corrosion						
K_{Iscc} ksi$\sqrt{in}$ (MPa$\sqrt{m}$)	95	(104.4)	U		U	

Coefficient of Thermal Expansion

6.1×10^{-6} in./in./F (RT to 800°F) [1.10×10^{-5} m/m/K (700K)]

Density

0.285 lb./in.^{3} (7.89 Mg/m^3)

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.
(b) Double-shear pin-type specimen; average of three tests in each direction.
(c) U, unavailable; NA, not applicable.
(d) Average of three tests in each direction.

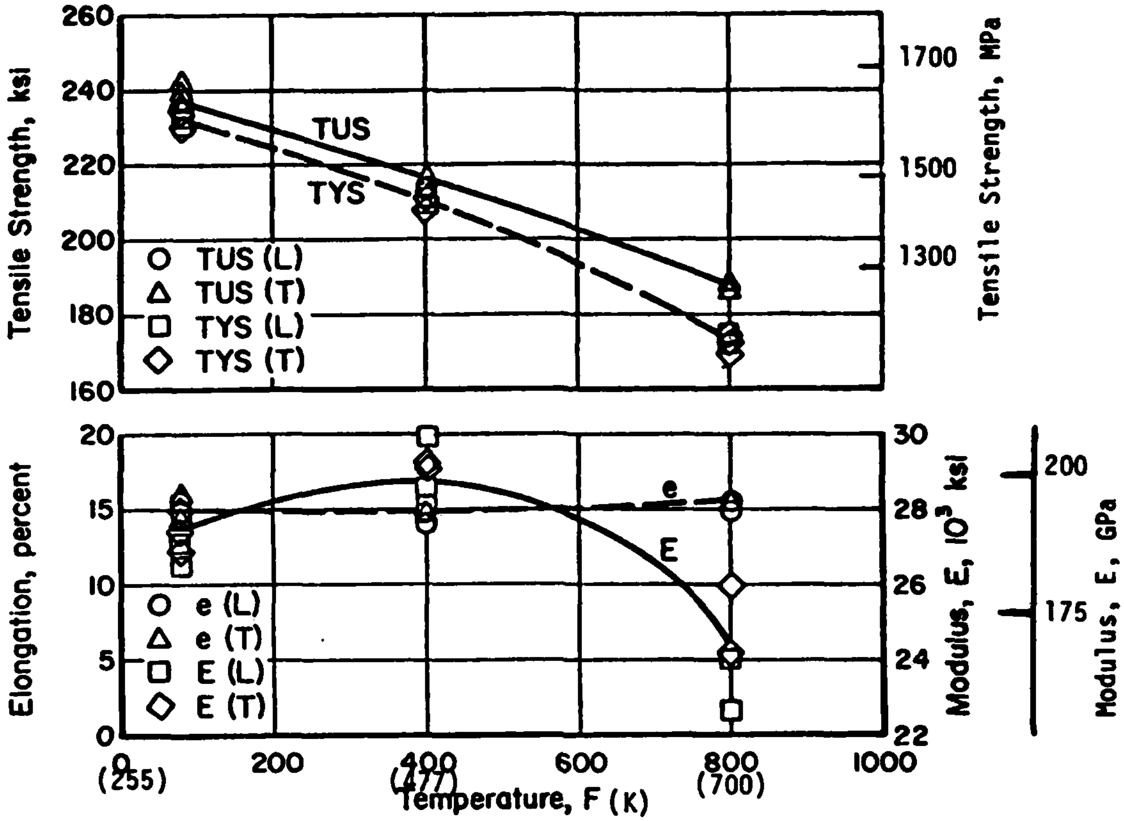


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

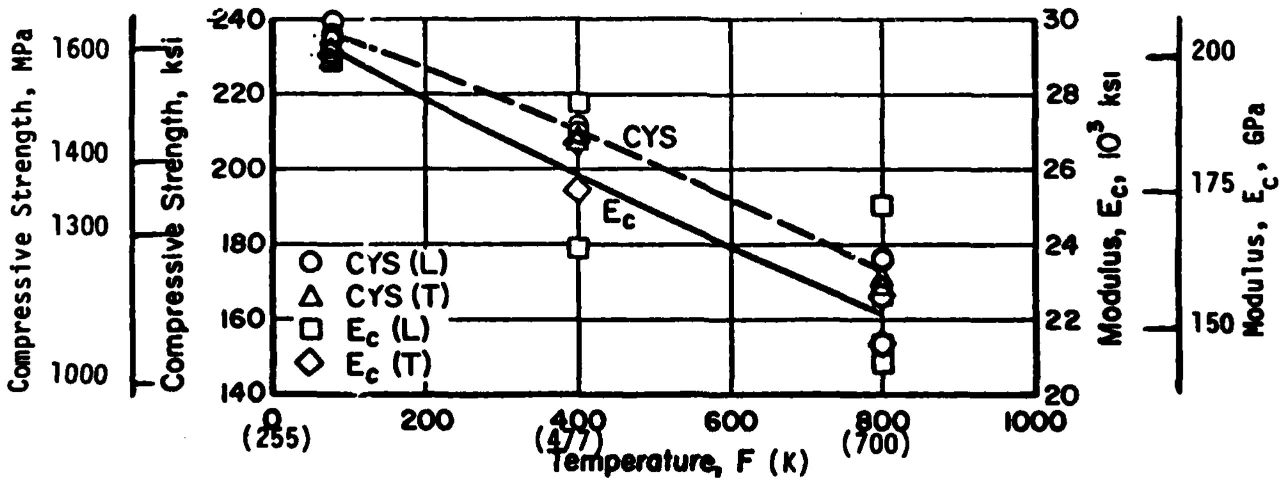


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

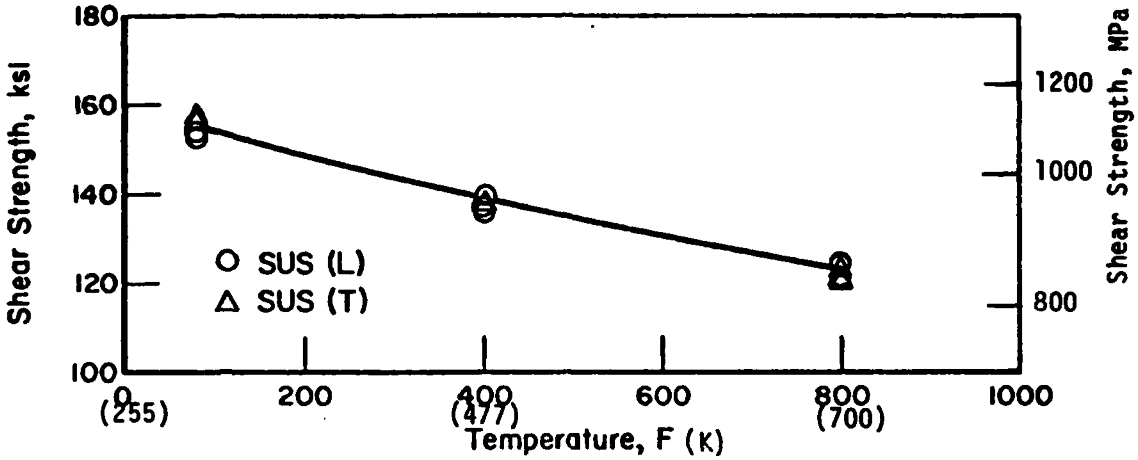


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

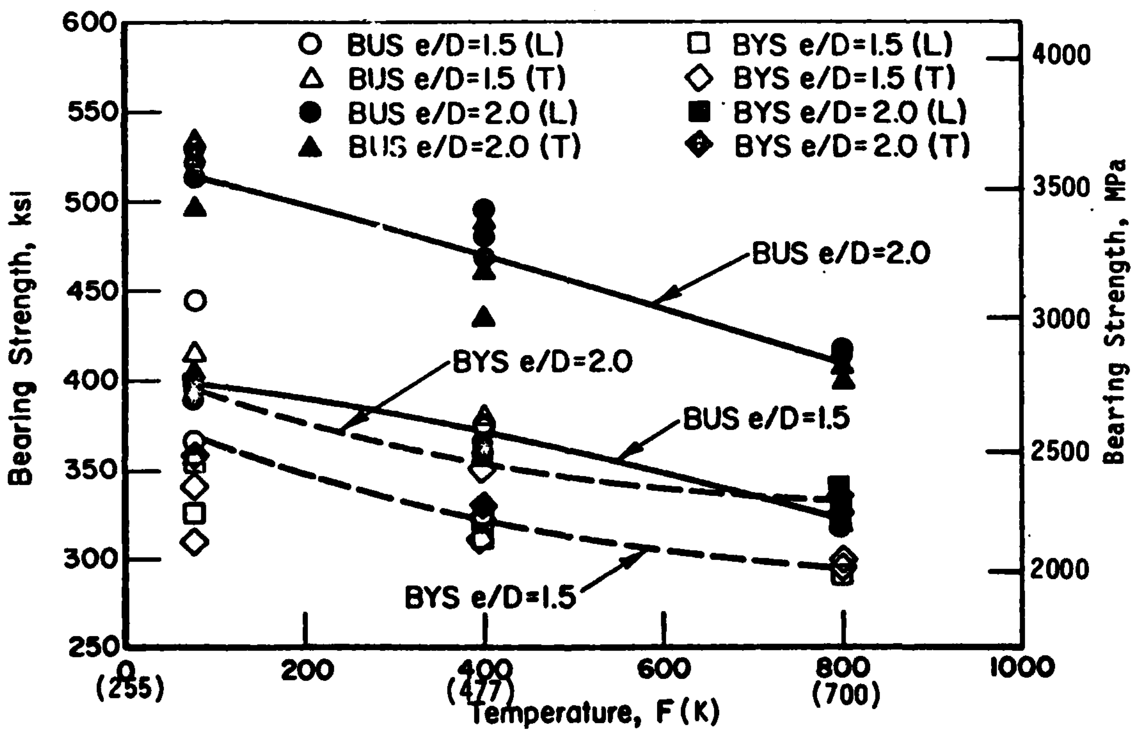


FIGURE 4. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

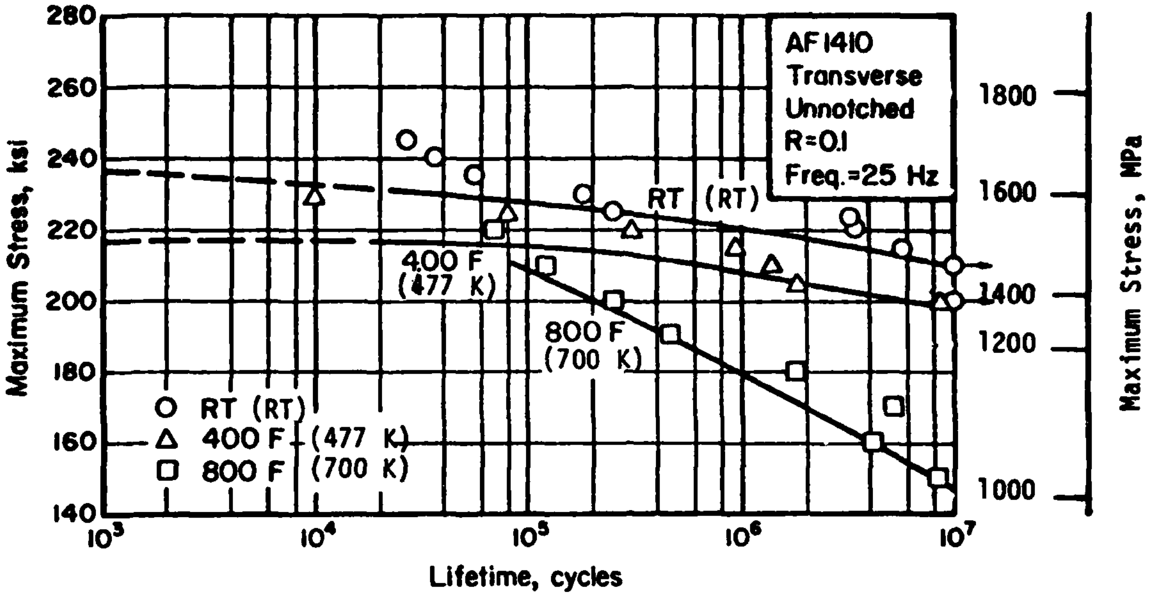


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

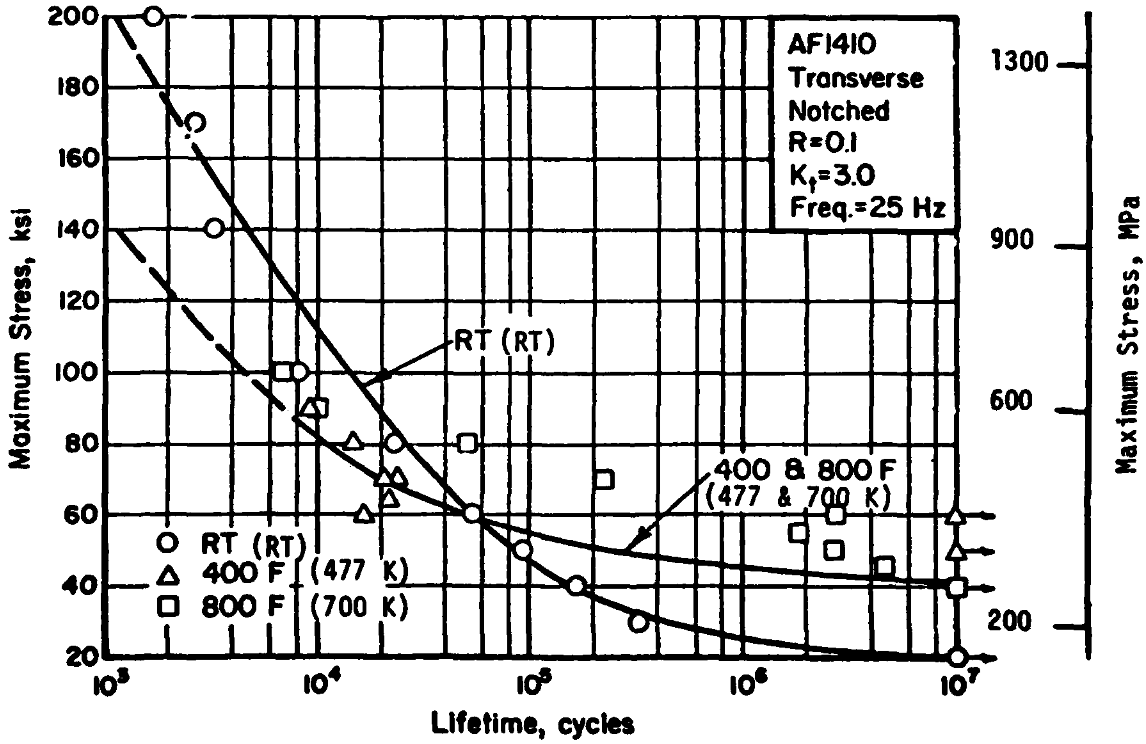


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

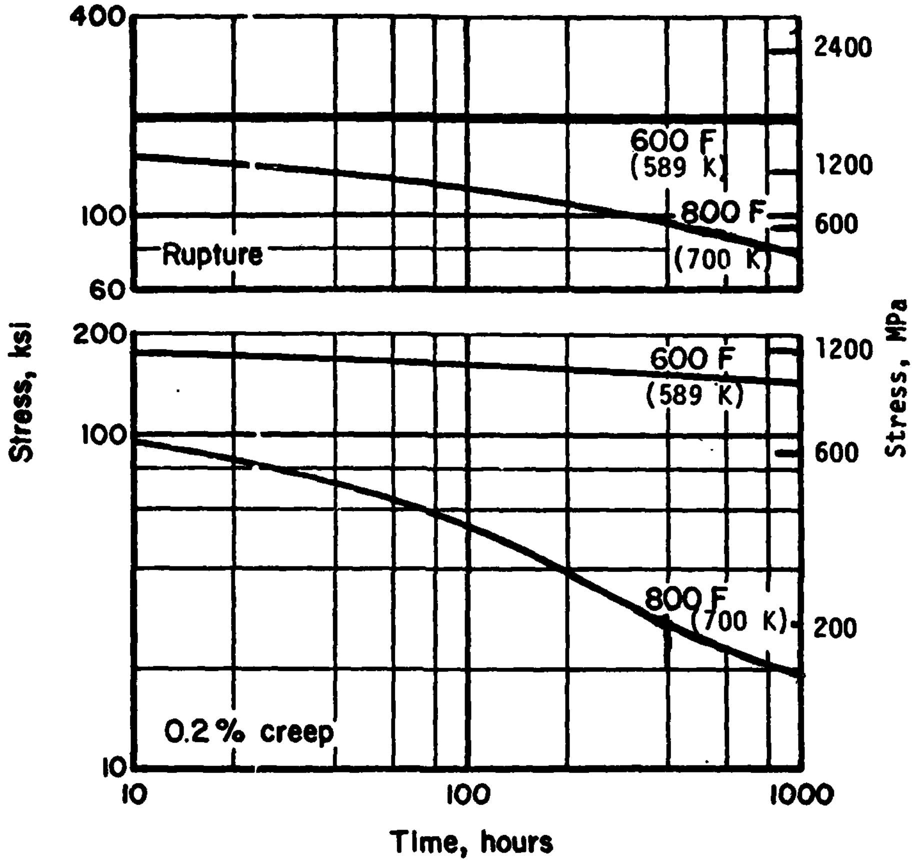


FIGURE 7. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR DOUBLE AUSTENITIZED AND AGED AF 1410 STEEL PLATE

MECHANICAL-PROPERTY DATA
AF 1410 (10Ni Modified) STEEL

DOUBLE AUSTENITIZED AND AGED DIE FORGING

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-75-C-5065

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-75-C-5065. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Dr. David Snediker. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth, Technical Manager, Engineering and Design Data.

Notices

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any potential invention that may be in any way related thereto.

Approved for public release; distribution unlimited.

Copies of this report should not be returned unless return is required by security consideration, contractual obligations, or notice on a specific document.

AF 1410 Die Forging

Material Description

This material is the result of a cooperative development program by General Dynamics and U.S. Steel under the sponsorship of the Air Force Materials Laboratory. The development requirement was for a weldable high strength steel alloy, possessing a combined high fracture toughness and stress corrosion resistance.

Considerable information and data for AF 1410 is contained in the final report on Contract F33615-73-C-5093, AFML-TR-75-148, "Development of a Weldable High Strength Steel", September, 1975.

The Material used for this evaluation was from the above program.

Processing and Heat Treating

The die forging was double austenitized and aged as recommended in AFML-TR-75-148. This is 1650 F (1172 K), WQ + 1550 F (1116.5), WQ, and aged at 950 F (783.15 K), 5 hours, RAC.

AF 1410 Alloy Data[a]

Condition: Double Austenitized and Aged
Thickness: Various

Properties	Temperature, F (K) RT	(RT)	400	(477)	800	(700)
Tension						
TUS (longitudinal), ksi (MPa)	232.6	(1603.8)	209.3	(1443.1)	181.2	(1249.4)
TYS (longitudinal), ksi (MPa)	229.9	(1585.2)	201.9	(1392.1)	171.1	(1179.7)
e (longitudinal), percent in 1 in. (25.4 mm)	15.0		14.0		16.0	
RA (longitudinal), percent	64.6		62.1		68.9	
E (longitudinal), 10^3 ksi (GPa)	29.2	(201.3)	27.9	(192.4)	25.3	(174.4)
Compression						
CYS (longitudinal), ksi (MPa)	229.9	(1585.2)	201.1	(1386.6)	167.7	(1156.3)
E_c (longitudinal), 10^3 ksi (GPa)	29.7	(204.8)	27.2	(187.5)	24.9	(171.7)
Shear[b]						
SUS (longitudinal), ksi (MPa)	134.9	(930.1)	118.6	(817.7)	100.6	(693.6)
Impact						
V-notch Charpy, ft.lbs. (Joules) (longitudinal)	10.2[d]	(13.8)	U[c]		U	
Axial Fatigue (longitudinal)						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	230	(1585.9)	U		U	
10^5 cycles, ksi (MPa)	190	(1310.1)	U		U	
10^7 cycles, ksi (MPa)	175	(1206.6)	U		U	
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	105	(724.0)	U		U	
10^5 cycles, ksi (MPa)	45	(310.3)	U		U	
10^7 cycles, ksi (MPa)	20	(137.9)	U		U	
Stress Corrosion						
80% TYS, 1000 hrs. maximum	No Cracks[e]					
Coefficient of Thermal Expansion						
6.1×10^{-6} in./in./F (RT to 800 F)	[1.10×10^{-5} m/m/K (700 K)]					
Density						
0.285 lb./in.^{3} (7.89 Mg/m^3)						

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests.

(e) Alternate immersion, 3.5% NaCl.

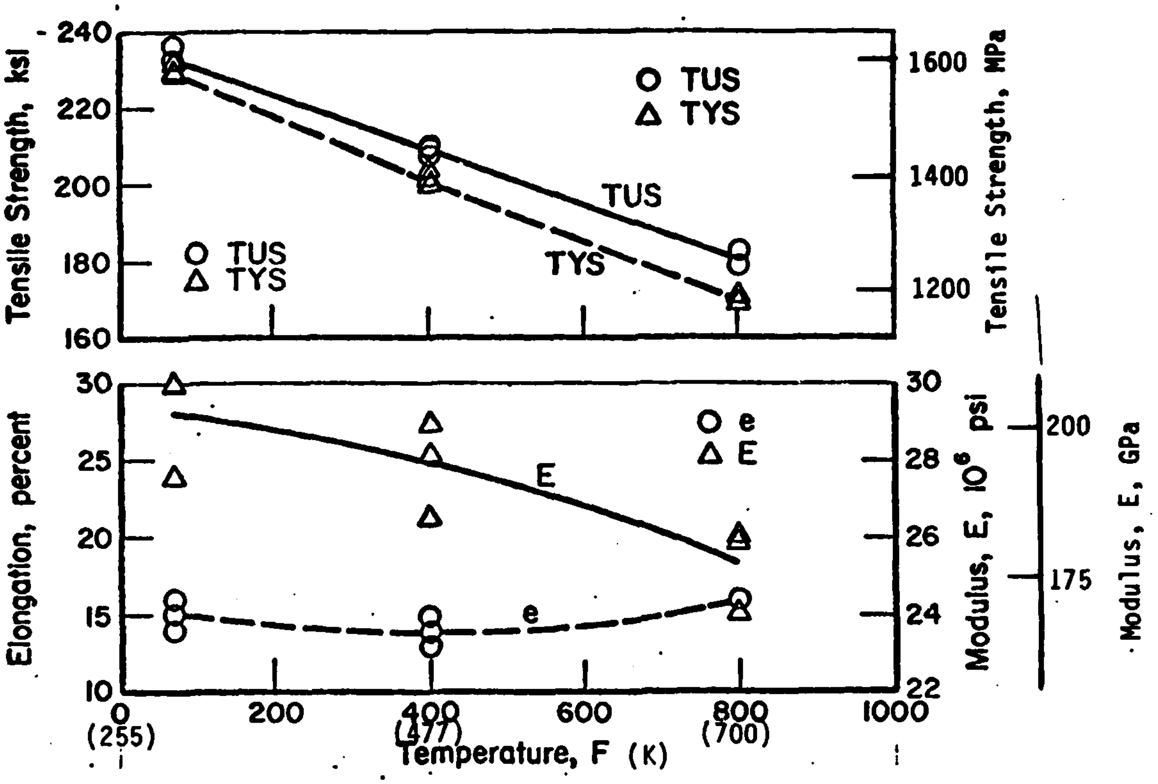


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF 1410 DIE FORGINGS

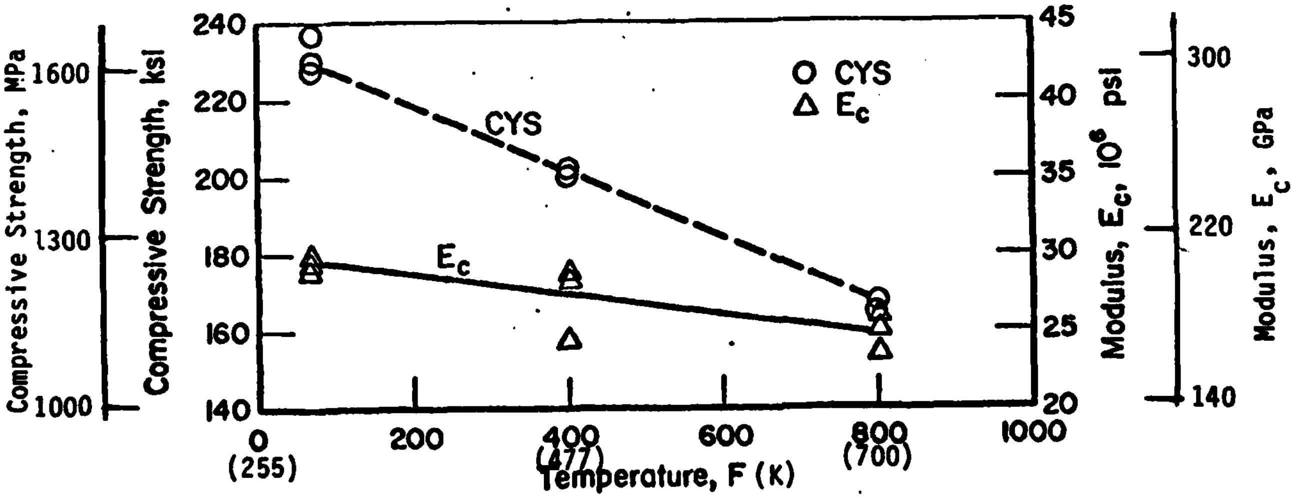


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF 1410 DIE FORGINGS

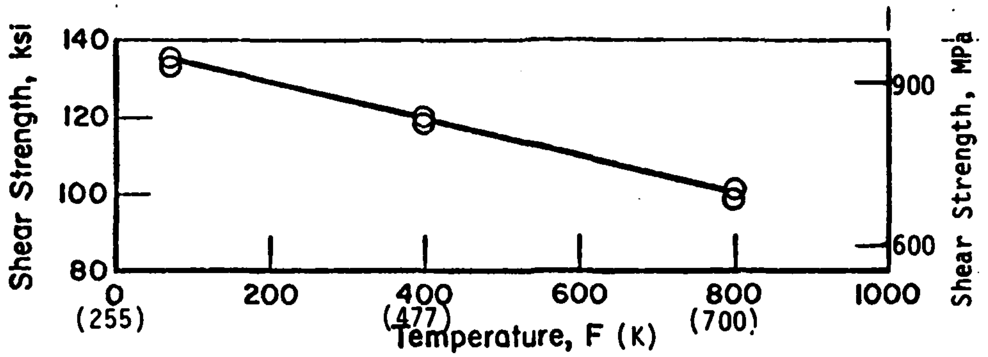


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF AF 1410 DIE FORGINGS

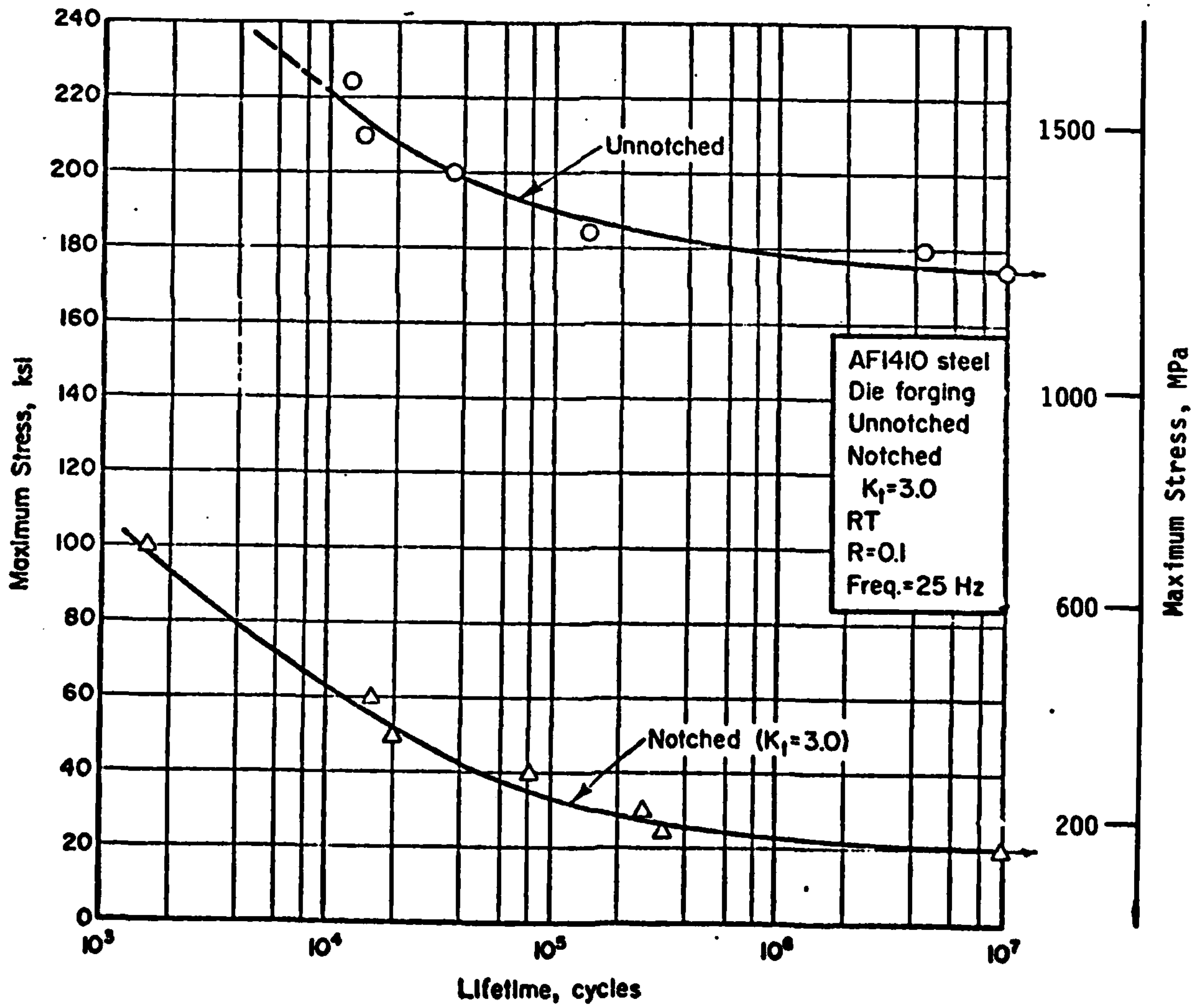


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED AND NOTCHED AF 1410 DIE FORGINGS AT ROOM TEMPERATURE

U.S. GOVERNMENT PRINTING OFFICE: 1980-659-062/674